COLOUR.

BY

C. T. WHITMELL

PRICE:

To Subscribers . . . . [illegible]

To Non-Subscribers . . . [illegible]

*As the Title of this Book is nearly the same as that of a *Book by Professor Church, I propose to avoid any confusion by altering the Title to*

"COLOUR-SCIENCE".

* "COLOUR: an Elementary Manual for Students."—(Cassell & Co.) To this valuable work, with its excellent coloured-plates, I am much indebted, and can strongly commend it to those interested in the subject. Professor Rood's able treatise, "MODERN CHROMATICS."—(Kegan, Paul & Co.), may also be consulted with great advantage.

ERRATUM.

In 3rd line of Preface,—*for* principle *read* principal.

COLOUR,

AN ELEMENTARY TREATISE,

BY

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TRINITY COLLEGE, CAMBRIDGE.

WITH SIX PLATES.

1888.

WM. LEWIS, BOOKSELLER, 22, DUKE STREET, CARDIFF.

And thou shalt make a veil of blue, and purple,
and scarlet, and fine twined linen.
Exodus xxvi, 31.

Ergo Iris croceis per cœlum roscida pennis,
Mille trahens varios adverso sole colores,
Devolat. *Verg. Æn. IV. ll. 700-2.*

This minion, a Coluthus, writ in red
Bistre and azure by Bessarion's scribe.—
R. Browning.

TO

T. H. THOMAS, R.C.A.,

PRESIDENT OF THE CARDIFF NATURALISTS' SOCIETY,

AND

CHAIRMAN OF THE SOUTH WALES ART SOCIETY

AND SKETCHING CLUB (1888),

THIS LITTLE BOOK IS

DEDICATED BY HIS

FRIEND, THE

AUTHOR.

PREFACE.

IN the following pages an attempt is made to give a brief and systematic account of the principle phenomena connected with Colour.

The scientific side of the subject occupies the greater part of the book, and will be found mainly in Parts I. to XI. The artistic side, which I trust has not been unduly neglected, will be found mainly in Parts XII. to XVI. But no strict separation is possible.

I have not hesitated to describe in detail a good many experiments on Colour, in the hope that some readers may be induced to practically take up and extend our knowledge of this fascinating field of inquiry.

For most of the experiments the apparatus required is simple and cheap; and matters which may appear dry and difficult to understand in reading, will be found to wear a quite new aspect when tested experimentally.

The low price, at which the book is published, has made it impossible to supply *coloured* plates, but, in the case of most of the diagrams given, it will be seen that colouring is not essential to the points they are intended to illustrate.

Instead of an INDEX, a full TABLE OF CONTENTS is prefixed, and the headings and numbering of the Sections will, I hope, make it easy to use the frequent cross-references connecting those portions of the subject which throw light on one another.

For recent researches on Colour Photometry, on the Transmission of Sun-light through the Atmosphere, and on the Permanence of Pigments, reference should be made to the Appendix, and it would be well to read this Appendix in connection with the Sections to which it refers.

Colour is in such intimate relation with so many other subjects that it has been far from easy to decide what to include and what to exclude, but an endeavour has been made to take a comprehensive view.

Another difficult point is how to classify and sub-divide the subject. A good classification, while it avoids repetition on the one hand, should facilitate reference on the other. But, in a book, intended rather for the general, or the artistic, reader, than for the scientific man, a certain amount of repetition may not be altogether disadvantageous.

No two works, that I have consulted, agree in their plan, so that I have been obliged to form my own scheme, which, however is largely

based upon the lines of Professor Rood's valuable work—Modern Chromatics. To this book, and to the equally valuable work by Prof. Church (Colour, an Elementary Manual for Students), I am deeply indebted, and have made frequent acknowledgments of the obligations I am under.

I wish also to express my indebtedness to the works of the following writers, some of whom have furnished me, by correspondence, with matter of great interest, not previously published.

Capt. Abney, Sir D. Brewster, W. Benson, A. C. Becquerel, Sir J. Collier, Prof. Church, Chevreul, C. Darwin, Deschanel, Capt. Dutton, Prof. Everett, Prof. M. Foster, Goethe, R. T. Glazebrook, Prof. Garnett, J. Gorham, Prof. A. Geikie, Prof. Huxley, Prof. Holmgren, Sir J. Herschel, Prof. Helmholtz, Rev. H. Haweis, Prof. Hering, Prof. Jamin, Dr. A. Koenig, Clarence King, Prof. Lommel, Dr. N. Lockyer, Prof. Landois, Prof. LeConte, Sir J. Lubbock, Dr. Lloyd, Prof. Langley, Prof. Maxwell, Prof. W. A. Miller, Prof. W. H. Miller, Sir I. Newton, H. Power, Dr. A. C. Peale, Prof. Powel, Dr. Pole, A. Penley, Prof. Rood, Lord Rayleigh, Dr. C. Roberts, R. Routledge, J. Ruskin, Sir. H. Roscoe, Prof. G. G. Stokes, Dr. Spottiswoode, R. H. Scott,

Dr. Sorby, Prof. Tyndall, J. Scott Taylor, T. H. Thomas, L. Wright, Dr. H. Watts, Dr. T. Young.

In revising the proof-sheets I have been greatly aided by Mr. T. H. Thomas, who has also favoured me with valuable hints in connection with the artistic side of the subject.

To the numerous friends, who, by becoming Subscribers, have made possible the publication of this book, I am very grateful. Corrections and criticisms will be thankfully received.

Lammas Day, 1*st August*, 1888.

18, PARK PLACE, CARDIFF.

ERRATA.

Page	33	*for*	aluminum	*read*	aluminium.
,,	121	,,	interse	,,	*inter se.*
,,	135	,,	explantion	,,	explanation.
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COLOUR.

PART I.—THE NATURE OF COLOUR.

1. *Colours are sensations and have no objective existence apart from the seeing eye.*—Colours are Sensations excited (usually by Light) upon the retina of the eye. The sensation of colour may be excited by an electrical or a mechanical stimulus, but this method of excitation need not be considered now. Suppose the object looked at to remain unchanged, there are two things capable of variation, the eye, and the light which illuminates the object. Vary the colour or brightness of the incident light and we alter the colour or brightness of the object. Green wool held in the red of the spectrum looks black. Vary the arrangement to the eye. A gray patch upon a green ground looks pink, upon a black ground white. Alter the state of the eye by looking for some time at a brilliantly coloured surface, and then, on looking at other objects, their colours will appear changed. The extreme case of change in the eye is afforded by colour-blind people. So colours are not inherent fixed qualities of bodies.

2. *Similar and Dissimilar Colours.*—Nor are colours strictly indicative of some distinctive optical quality of light, such as wave-length. Light of one and the same wave-length may have different colours to different eyes, and under different circumstances to the same eye. Mixtures of two different colours may produce the same colour-sensation. Blue and yellow lights mixed produce white, so do

red and blue-green, and so also do all the colours of the spectrum taken together. The eye cannot distinguish the different components of these white lights.

Prof. Helmholtz thus states the law of correspondence between what is subjective and objective in vision :—Similar lights produce, under like conditions, similar sensations of colour. Lights, which, under like conditions, excite unlike sensations of colour, are dissimilar.

Outside ourselves there is no such thing as colour ; we have only mechanical movements, undulations in the Ether of Space ; and it is easy to imagine beings, destitute of all sense of colour, in whom the radiant energy would produce only the sensation of heat. Light is itself invisible, and we are unaware of its existence when its path meets no material object. Particles of dust, water, smoke, etc., reveal the presence of the light by themselves becoming visible.

3. *Transparency, etc.*—Bodies are *transparent* when objects can be clearly seen through them ; *translucent* when they allow light to pass imperfectly, so that objects cannot be clearly seen through them ; and *opaque* when they wholly shut off light. No known substance is perfectly transparent or perfectly opaque. Clear glass stops some of the rays, thin gold leaf transmits some. Ground glass and thin porcelain are translucent.

4. *Light and the Ether. An optically simple colour.*—Light—like Sound—when viewed objectively, consists of certain vibrations of a medium (the ether). The simplest kind of light, like a pure tone in sound, consists of a regular periodic succession of similar vibrations. The extent of a vibration determines the intensity or brightness of the light, the rapidity of the vibration is connected with the colour of the light. Waves of a particular length will, under similar circumstances, give to the same eye one and the same colour sensation. A red body is one, which, under normal conditions, gives to a normal eye the sensation of red. An optically simple colour is produced by vibrations of any one given period, and corresponds to waves of one given length.

5. *White Light.*—Ordinary white light is a complicated mixture of all the waves whose vibrational periods allow them to be seen. The colours given by these waves range from deep crimson, with a wave-length of about one thirtyfive thousandth, to pale violet, with a wave-length of about one sixtyeight thousandth, of an inch. The average length of a wave of white light may be taken as about one fifty thousandth of an inch.

In what follows, when no particular light is specified, Daylight is supposed to be used. The electric arc-light, the magnesium-light, and the lime-light, resemble daylight, but the two first are relatively richer in violet rays; whilst gas-light, candle-light, and a not very highly heated incandescent electric carbon filament, are poorer than is daylight in the blue and especially in the violet rays, but in other respects resemble it.

Attempts have been made to construct an instrument which shall give what may be called a standard white light; and a lamp, devised by Mr. Harcourt, gives, very approximately, such a light.

The *local*, or *proper*, colour of an object is that which it shows in common daylight. The *illumination* colour is that which is produced by coloured light. Red sandstone in daylight is an example of proper colour. A snow mountain at sunset shows an illumination colour.

6. *Complexity of Causes producing Colour.*—Suppose a piece of coloured drapery hanging in a room lighted by sunset. The hue of the drapery is due, not only to its dye, but also to the kind of light falling on it through the window and reflected on it from the various coloured objects in the room. The nature of the surface of the stuff and the angle at which we view it, also affect the result; so that the ingenuity of the artist may well be taxed to the utmost to correctly reproduce the tints, especially when we bear in mind that he has only paints to work with, and that these are so much inferior to coloured light.

PART II.—THE PRODUCTION OF COLOUR.

7. *Self-luminous bodies. General and selective radiation.*—To be visible bodies must be either self-luminous or illuminated. An incandescent solid—say a platinum wire, a carbon filament, or a ball of lime—as its temperature rises, gives out first a red, then an orange, then a yellow, and lastly a white, light; shorter waves being added to longer ones as the heat increases. Incandescent liquids resemble incandescent solids in their radiation. Radiation of the kind just described is called *general* radiation. At a very intense heat the emitted light tends to violet.

Incandescent gases in many cases give out light containing waves of only certain particular lengths; sodium vapour emitting a brilliant yellow light, lithium a red light, thallium a green light, and so on. This kind of radiation is called *selective.*

8. *Illuminated objects, seen by various lights.*—Illuminated objects are seen by borrowed light, that is by the light they reflect. Their colour depends upon the nature of the incident light, and also upon the way in which they act on it, either generally or selectively. A body which reflects equally all colours appears of the same colour as the light which illuminates it. If this light is daylight, the body will appear white. If its reflecting power is gradually but equally reduced, or, if the light itself be gradually darkened, the white becomes gray, and, finally, when no light is reflected, the body looks black. But the majority of bodies reflect some rays in larger proportion than others, and hence appear coloured with a hue due to the mixture, or sum, of he reflected rays.

To test what coloured rays an object reflects, a narrow strip of it should be viewed through a prism, and its spectrum may then be compared with that of a white strip seen through the same prism. The former spectrum will show by its deficiencies what colours are wanting. The direct vision spectroscope is the most convenient instrument for comparing spectra together. Daylight is our normal illuminant for estimating colours. If we use gaslight, which compared with daylight is deficient in blue and violet, many of us find a difficulty in distinguishing blues and greens. If monochromatic sodium light is used, colours can no longer be distinguished. The living face looks dead, and a rose and its leaves differ only in form. A world lit up by a sodium sun would be dull indeed. (Sect. 110.) It is obvious that a body cannot exhibit a certain colour, unless the rays, corresponding to that colour, are contained in the light which illuminates it.

"A."

9. *Colour due to Prismatic Dispersion. The Solar Spectrum.*—The Rainbow owes its colours to the dispersive power of water, which separates out the light waves according to their various lengths; but the sun, not being a point of light, the colours are not pure. To produce a pure set of colours a glass prism is used, and the sunlight is admitted through a narrow slit parallel to the refracting edge of the prism. A prism containing carbon bisulphide gives a splendid spectrum. Newton carefully studied the Solar Spectrum, as the coloured band of light is called, and named the colours red, orange, yellow, green, blue, indigo and violet. It is easy to recognise, without going into detail, six colours, red, orange, yellow, green, blue and violet. The colours of a pure spectrum are simple colours, that is to say, they are optically undecomposable. Select any small portion, pass its light through a second prism, and it emerges unchanged, except in direction. The waves are longest at the red end, shortest at the violet, and the steps of change from one hue to another are insensible.

Considering the colours more minutely, we find dark crimson, scarlet, orange, yellow, greenish yellow and yellowish green, green, bluish green, marine, greenish blue, blue, violet blue, and violet. (I venture to suggest the word *marine* as a name for the colour which is, as it were, exactly between green and blue, a colour sometimes called sea-green, blue-green, or green-blue.)

The brightest portion is that about the yellow; green and scarlet are fairly bright; blue and violet are the darkest part. Types of every existing colour (except purples) occur in the spectrum. In an ordinary spectrum, produced by a glass prism, out of 1,000 parts, about 150 are red, 10 yellow, 100 green, 300 blue, and 200 violet. Equal changes in wave-length do not produce equal changes of hue, the eye being far more sensitive to changes of wave-length near the greenish yellow part of the spectrum than at either end. (Sec. 127.)

10. *The Diffraction Spectrum.*—In the spectrum, produced by a glass prism, the blue-violet portion is much longer than the red, and the yellow portion is situated about one quarter of the total length from the red end. In the spectrum (usually called the normal spectrum) produced by a diffraction grating, the blue-violet and red portions are far more nearly equal, and the yellow is nearer the middle. In both the prismatic and the diffraction spectrum, those colours, to which we give different names, are unequally spaced.

11. *The Fixed Lines.*—The solar spectrum is crossed by a number of fine black lines A, B, C, etc. (Fraunhofer lines), which are fixed in position, and form a most valuable series of marks, by which accurate reference can be made to any part of the coloured band. We find in the red portion A, B, C; in the yellow D; in the green E, b; in the marine F; in the blue and violet G, H. The solar spectrum is our most convenient and unalterable standard of reference for colour. (See Plate I. in connection with Sections 9, 10, 11.)

12. *Colour-change due to movement.*—If a body, such as burning sodium, giving out only a simple series of waves, seen as yellow, could be made very rapidly to approach the eye, a change of colour would be produced, the same as if the waves were shortened, and the yellow would become greenish. On the contrary, if the body receded very rapidly, the colour-change would be one corresponding to a lengthening of the waves, and the yellow would become reddish.

13. *Chromatic identity, and optical difference.*—If prismatic analysis be applied to a coloured flame, we see spread out in the spectrum the colours which (without analysis) reach the eye simultaneously. A flame coloured by strontium, for example, exhibits bands coloured red orange and blue, the bands being separated by dark spaces. White light is always compound, but not all white lights contain all the colours of daylight; sometimes not more than three or two colours are contained in a given white light. Each of the coloured lights of the spectrum is simple, but most coloured lights, even though to the eye they may exactly match one of the lights of the spectrum, are optically compound. *Chromatically* tested—that is by the eye—colours may agree, which *optically* tested—as by a prism—are different.

14. Yellow, for example, may be simply the non-decomposable spectral yellow, which is represented by waves all of about the same length; or it may be composed of the spectral red and green (without any spectral yellow). These two yellows then are chromatically identical, but optically different. (Sect. 124.) The optical properties of light are those which have reference to its origin and propagation through media, before it falls on the retina; the chromatic properties are those which have reference to its power of exciting certain sensations of colour, perceived through the eye. The distinction is of great importance.

15. *Pigments and the Spectrum.*—Certain pigments very fairly represent the spectral colours. Vermilion, washed over with carmine, will imitate the red, red-lead the

reddish orange. Orange and yellow may be represented by cadmium and chrome yellows. Emerald green, made yellowish or bluish, represents the yellow-green, green, and greenish-blue. Vert de cobalt is a fairly good marine: prussian-blue a greenish blue; cobalt a blue with less green: genuine ultramarine a good blue; artificial ultramarine a violet-blue. Hofmann's aniline blue-violet represents pretty well the violet, and this may also be imitated by artificial ultramarine washed with Hofmann's violet. Good purples can be found in the aniline colours, and ultramarine with madder carmine will also furnish purples; but the colours of natural bodies are never pure as are those of a pure spectrum.

"B."

16. *Colour produced in transmission.*—Colours are produced in the transmission of light through transparent bodies, such as stained glass, gelatine films, and coloured liquids. A body, equally transparent to all colours, does not of course alter the incident light. But if the body is more transparent to some colours than to others, it appears coloured with a hue due to the sum total of the rays transmitted. Nothing is added, but certain rays are stopped; this is *differential absorption.* (It is assumed here for simplicity that the surface reflection is the same for all colours.) Stained glass, placed upon a black surface, can be seen only by the general surface reflection, and it looks (in daylight) white; but, held in front of a white surface, it looks coloured, as we now see it by transmitted light. The colours resulting from the transmission of light through transparent coloured substances are much the most brilliant we can produce, and far surpass those of ordinary pigments. If we compare together the spectrum of white light, and the spectrum of the same light after transmission through a coloured glass, it will be found that even the most freely transmitted colours are dimmer in the second spectrum than in the first. The red transmitted through a red glass is

dimmer than the red seen without the glass. (Sect. 24). White light sent through a red glass emerges as red light, but it is not bodily turned into red, it is red simply because the glass (acting like a sieve) allows only the red waves to pass through. This is easily proved by placing the glass in the path of the rays forming a spectrum, or by viewing a spectrum through the glass, or by testing the transmitted light by a spectroscope.

17. *Such colours seldom optically pure.*—Very few media, however, transmit colours which are optically pure, that is to say, light which is only of one wave-length. It will be found that the yellow light, which emerges from a yellow glass, contains, not only yellow, but also red and green, when it is analysed by a prism. Most green glasses let through a good deal of blue; most blue glasses a good deal of green, and very often some red. It is remarkable how small an absorptive effect gives rise to a vivid hue; a certain magenta-coloured gelatine film, for example, stops out only the green; so that the sum of all the other colours in white light is what we term magenta.

17A. *Details connected with absorption.*—I give here the composition (ascertained by a direct vision spectroscope) of the light transmitted through certain red yellow green and blue glasses, etc. The absorbed colours can be obtained by subtracting the transmitted colours from the total of the spectral hues. *Red;* through one plate, red, and some orange slightly darkened, and a little darkened green and blue; through two plates, red only, darker than before; through three, very dim red, only the less refrangible half seen. The three glasses look dark red. (Plate II.) *Yellow*; one plate, red, yellow, and most of the green slightly darkened; two plates, red, darkened yellow, and a little dark green; three plates, red darkened, yellow much darkened, trace of dark green. The three glasses look orange-coloured. *Green;* one plate, red darkened, only the more refrangible half seen, yellow darkened, green a little

dulled, marine darkened, and a little dull blue; two plates, trace of dark orange, green much darkened; three plates, only a dim green. The three glasses look dark green. *Blue;* one plate, dim red, yellowish-green slightly darkened, dark green and marine, blue and violet scarcely altered; two plates, very dim yellow-green, dark green, trace of dark marine, slightly darkened blue and violet; three plates, dark violet-blue. The three glasses look violet-blue. (Plate II.) For delicate photographic work, it is necessary to exclude the more refrangible rays, and for this purpose red or orange is better than yellow glass.

Composition of light transmitted through gelatine films may be now given. Through a rich *blue film;* violet, blue, the bluish part of the green, and some dull red. Through a *full yellow film;* red, yellow, green, and greenish-blue. Through a *magenta-coloured film;* red, orange, blue, and violet.

A series of solutions in flat sided glass bottles, each containing a thickness of about three quarters of an inch of iquid, gave the following results on examination of the transmitted light by a spectroscope. *Fuchsine* (magenta), strong deep red solution in alcohol; a deep red band. The same, weak puce-coloured solution in water; all the colours, except a dark band in the less refrangible green. *Ferric sulphocyanate*, deep red solution, transmits red and a little orange. *Murexid*, purplish red solution, transmits red and violet. *Aniline Scarlet*, colour reddish orange, transmits red, yellow, and a little green. *Potassium permanganate*, purple solution; red, yellow, blue, and violet. *Aurine*, orange solution; red, yellow, and green. *Potassium bi chromate*, orange solution; red, yellow, and a little green. *Aniline yellow;* red, yellow, green, and greenish blue. *Picric acid*, light yellow solution; red, yellow, green, and a little blue. *Potassium chromate*, light yellow solution; red, yellow, green, and a little blue. *Mixed chromic chloride* and *potassium bichromate*, brown yellow solution, transmits red and green, but not yellow. *Fluorescin*, orange-yellow

solution; red, yellow, and green. Fairly bright green solution, *copper sulphate* and *potassium bichromate*, transmits orange, red, yellow, green, and blue. Dark green solution, *ammoniacal sulphate of copper* and *potassium bichromate* transmits most of the red (darkened), yellow (darkened), green, and greenish blue. Grass-green *chlorophyll* transmits red (except a dark central band), yellow, green (faintly banded), and blue. Olive green solution of *chromic chloride;* red, green, and blue (less refrangible). Bluish green solution of *chrome alum;* red, green, and all the blue. Light greenish blue solution of *aniline* (Victoria green) transmits all red (except a little of the more refrangible), yellow, green, blue, and violet. Light blue *copper chloride;* orange-red, yellow, green, blue, and violet. Blue solution of *copper sulphate;* orange-red (a little), yellow, green, blue, and violet. Rich blue *indigo;* less refrangible red, green, blue, and violet. Rich deep *aniline blue*; dull extreme red, bluish-green, blue, and violet. Deep blue *ammoniacal copper sulphate;* middle and more refrangible green, blue, and violet. Purple *litmus* (solution) transmits most of the red (except more refrangible), green, blue, and violet. *Hofmann's Violet* (*BB*), (solution purple), transmits less refrangible red, bluish-green, blue, and violet. *Hofmann's Violet* (*RRR*) (solution red-purple), transmits red, more refrangible green, blue, and violet.

The above examples show the complexity of the colours transmitted by coloured solutions.

It may be useful to state a few of these results from the other (absorption) side. To absorb the red, we may use solution of copper sulphate; to absorb the yellow, litmus; the green, potassium permanganate; the violet, weak solution of potassium chromate. With regard to the blue, I do not know of any substance which will absorb blue only; but potassium bichromate will absorb both blue and violet; and magenta (fairly strong) will absorb both blue and green.

17B. *Absorption Curves.*—Graphical representation of the colours transmitted by a given substance is very

convenient. Take an oblong rectangle to represent the solar spectrum. Let abscissæ be taken horizontally along the lower edge, and erect at each point ordinates representing the luminosity of each colour transmitted; in this way we get a curve; and the area, enclosed between this curve, the extreme ordinates, and the base line, represents the transmitted light. (Plate II. represents graphically the light, transmitted through red glass, through blue glass, and reflected from a green leaf.)

18. *Incompetency of the eye to decide whether a colour is optically simple or not.*—As was previously stated, the unaided eye is quite incompetent to decide upon the optical constituents of a colour; spectroscopic analysis is needed. The details just given well illustrate the above statement.

19. It was mentioned that certain self-luminous bodies may give out definitely coloured light. A light may be red because the luminous substance may only be competent to vibrate at that particular rate which gives us the sensation of red. But we see also that light from a white source may be made red by passing through a red glass, because the glass stops out all rays but the red ones. In the former case we have an *effect*, in the latter a *defect*, as it were. Red-fire will exemplify the former, the setting sun the latter.

20. *Effect of increasing the thickness of an absorbent medium.*—When the medium increases in thickness in arithmetical progression, the intensity of the coloured light decreases in geometrical progression. The practical effect of this is that, if we place one behind another a series of similar plates of coloured glass, then each successive plate cuts off a smaller fraction than the plate immediately preceding it; the main action being due to the first plate. Let R, Y, G, etc., represent the intensities of the several principal colours composing the incident white light, the total intensity of the beam being therefore $R + Y + G + B + V$; also let r, y, g, b, v, be the fractions of these rays which pass

through unit thickness of a given absorbent medium; then the emergent beam will be $Rr + Yy + Gg + Bb + Vv$.

Now take a thickness of the medium, equal to n units, then the intensity of the beam emerging from this will be

$$Rr^n + Yy^n + Gg^n + Bb^n + Vv^n.$$

The terms of this expression containing the smallest of the fractions r, y, g, etc., will be those which decrease most rapidly as n (the thickness) increases; the colours corresponding to the larger terms will therefore relatively increase, and the emergent tint will not be white, but will exhibit a compounded colour depending on the relative magnitude of the several terms. If rays of any one colour, red for example, are less absorbed than the rest, it is always possible, by increasing the thickness of the medium, to obtain sensibly pure red only. But, if r, y, g, etc., differ but little from unity (as in the case of a neutral tinted medium), and the thickness of the medium is comparatively small, the emergent light will be dimmed, but not sensibly coloured. By looking through a wedge-shaped vessel, placed with its edge perpendicular to the slit, used for the spectrum, the progressive increase of the absorption may be seen at one view.

21. *Dichroic bodies.*—If the incident light be simple in character, it will of course only be darkened by increasing the thickness of the absorptive medium. If it be compound, and the absorptive medium act equally upon the constituents it absorbs, the transmitted light will again only be darkened as the thickness is increased. But, if the medium act unequally upon the constituents it absorbs, then the hue of the transmitted light may be completely changed by a change of thickness in the medium. Probably all substances do act unequally, but the action is much more pronounced in some than in others.

For example, *chromic chloride* solution, in small thickness is dirty green, in large red, because the green is more rapidly absorbed than the red as the thickness is increased. (A wedge-shaped bottle is very convenient for observing these

phenomena). Such a liquid is called *dichroic*. Dichroism, produced by alteration in thickness, is very common, and it is important for painters to bear in mind that, in diluting a colour, its hue may be much altered, not only in degree, but in kind. A deep tint of a pigment may match the deeply tinted portion of some object, but the pale tint of the pigment may be far from matching the pale tint of the object. (Sects. 36, 204.)

Dichroism is also used to denote a phenomenon depending upon variation in absorption not due to increase of depth, but to the relation between the polarisation of the light and the axes of the crystals exhibiting the phenomenon. (See Sect. 66A. Pleiochroism.)

22. *Superposition of Media.*—Superpose two differently coloured media, say a yellow and a blue glass. Here we have a double sieve exerting a doubly absorptive or subtractive effect. The white light is twice sifted, and only those colours which can pass through *both* glasses are transmitted. We shall find that the transmitted light is green, for both yellow and blue glass (of the ordinary kind) allow green to pass through. Through a red and a green glass, properly chosen, no light will pass, for each stops the light transmitted by the other. With a certain red and green glass I find a brown transmitted, because the green allowed a little dulled red to pass. It is, I think, a mistake to put red claret into green glasses, the liquid looks like ink for the reason just given.

Knowing the colours transmitted by each glass, we can to some extent predict the colour transmitted through two or three glasses in succession. For instance, through a certain red and a certain yellow glass, we find that red only is transmitted; through red and blue, red; through yellow and green, greenish-yellow; through green and blue, marine. (The glasses used are those referred to in Sect. 17A.) Again, through a red and a blue glass (if the red transmit some blue and the blue some red) we get purple; but if the

red transmit no blue and the blue no red, there is opacity ; but if the blue transmit red, and the red no blue, the result is red. Finally, if the red transmit blue, but the blue no red, the result would be blue. It must be clearly understood that these results are in all cases due to subtractive, not to additive, action. Only the colours, which get through the double sieve, can mingle on the retina.

Aniline blue and ammoniacal copper sulphate form solutions nearly alike to the eye, both being a deep rich blue. Place behind each solution an orange-coloured solution of potassium bichromate. The aniline and bichromate pair transmit a deep red, the copper and bichromate pair a deep green. The reason is this : the bichromate, tested by the spectroscope, transmits red yellow and the less refrangible half of the green. Of these transmitted colours, only one—the green—and only the more refrangible part of that, can get through the copper solution ; whilst only the red, and only the less refrangible part of that, can get through the aniline solution. The green, which the aniline solution is able to transmit, is the bluish or more refrangible green, the solution being opaque to the middle and to the less refrangible green. The copper solution is quite opaque to all colours from red to less refrangible green inclusive, but it transmits the middle and the more refrangible green, and the blue and violet. Litmus (purple) solution and potassium bichromate (orange) solution, when superposed, transmit a yellow, which analysed by the spectroscope is found to contain only red and green, but no simple spectral yellow. Copper sulphate, potassium, bichromate, and potassium permanganate, solutions, superposed, transmit a yellow ; a yellow which, tested by the spectroscope, is found to be the simple spectral yellow. (Sect. 124.)

The order in which the media are placed is indifferent ; for only the colours unabsorbed by any of them can pass through them all. As media are added, colours are subtracted.

22A. *Coloured objects through Coloured media.*—The case of an ordinary coloured object viewed through a coloured medium is analogous to that of looking through two superposed coloured media; there is a doubly subtractive action. First, the absorptive action of the coloured object (explained in Sect. 29, etc.), causing the light which it reflects to be coloured light. Secondly, the absorptive action of the coloured medium (say, stained glass, or coloured liquid) upon this coloured light. If the coloured medium is opaque to all rays reflected by the coloured object, then the object will appear black. (I neglect here the surface reflection of white light.)

Through a *red* glass, red yellow and orange appear red, green blue and violet appear black, purple is a dark red. This glass practically transmits scarcely anything but red, so that, out of the rays reflected by the objects looked at, only the red is passed through. With a *yellow* glass (transmitting red yellow and green) red yellow and green objects are seen as such. Blues appear black if (like ultramarine) they reflect little or no green, and green if (like prussian blue) they reflect green. Violet looks black, and purple appears darker and redder, owing to the suppression of its blue element. Through a *green* glass (transmitting green darkened red and a little blue), reds look brown or black, yellow looks greenish-yellow, for as it reflects red green and yellow, and the glass darkens or shuts out the red, the remainder (green and yellow) will give the yellow-green colour. Orange looks olive-green. Greens and greenish-blues look green. Blues are dulled and, if they contain green, look greenish or green. Violet and purple look black. With a *blue* glass (transmitting blue violet and some green) red looks black. Orange looks olive green, and yellow looks green; for, of the colours reflected by orange and yellow, green is the only one transmissible by the blue glass. Greens look a bluer green, for they reflect blue as well as green, and this blue element is relatively strengthened. Blues and violets appear blue and violet.

Purple has its red removed and looks blue. With a magenta *purple* film, transmitting only blue and red, the following are the results. Red yellow and orange appear red. Green looks black. Marine looks blue. Blues appear a very deep pure blue, as all green is removed from them, and only the more refrangible blue is transmitted. Violets are violet, and purples purple. The effects are in all cases subtractive not additive. A magenta film produces remarkable and beautiful changes in the colours of flowers, etc., seen through it. Dark green leaves look purple gray, light green ones coral red. Yellow flowers become orange or scarlet, white ones purple, blue ones a deeper blue. The blue sky becomes of a deep violet colour, while the white clouds are purple. The changes thus produced indicate real differences in the objects looked at, differences which in some cases are not so well seen by ordinary light. (See also Sect. 27.)

23. In many coloured substances the absorption (tested by a spectroscope) is so definite and characteristic as to furnish a delicate test for their presence ; for examples, blood, potassium permanganate, chlorophyll, etc., may be taken. In a few cases the absorptive action of the medium is so narrowly restricted, or is so generally diffused, that there is next to no change, except a lessening of intensity, in the colour of the transmitted light. Salts of didymium exemplify the former supposition, alcohol and benzene the latter. If a substance absorbed two complementary colours (Sect. 128) it would be judged of by the eye as having no selective absorptive effect at all.

24. When white light is transmitted through a small thickness of a blue solution of sulphate of copper, we see a very diluted bluish green colour. If the solution is made stronger or thicker, the transmitted light becomes a purer deeper blue, but it does not contain more blue than before, only the other rays are more effectually cut off, so that the *relative* proportion of blue, in the transmitted beam, is

greater, the *absolute* amount being actually less. Similar remarks hold for other colours. (See Sect. 16.)

25. *Colour of Water. Effect of particles in suspension.*—In small thickness *water* is practically colourless. As the thickness increases, the red rays are absorbed, and the water looks of a blue-green or marine colour. This colour is best seen by half filling with water a horizontal tube whose ends are stopped by glass plates. We can then compare the colour of the light transmitted through the semicylinders of air and water respectively. With a tube 46 feet long, filled with pure water, the light transmitted was of a fine deep marine colour. The red rays were absent, the yellow were feeble, and the maximum brightness was in the green.

Pure water in a *deep* lake looks practically black (if we avoid the surface reflection of the sky) for the bottom of the lake is too dark to send light up to the eye, and all rays are absorbed. Scatter chalk into the water, and the water looks green where the chalk is plentiful, bluish-green and blue where it is less in quantity. The chalk provides a reflecting background, whilst the water by absorption changes the colour of the light by which we see the chalk. The Lake of Brienz is green; it receives the mud of two glacier streams. The Lake of Thun is blue, and is almost free from suspended matter. The Rhone, where it issues from the Lake of Geneva, is of a lovely turquoise colour, and is very pure. The Königsee in the Tyrol is of a beautiful green colour. The gyrating water of the whirlpool below the Falls of Niagara is of a bright emerald green colour. The geyser pools in the Yellowstone National Park (U.S.A.) exhibit rich blue, turquoise, marine, and green, colours, well seen against the white basins of geyserite. In richness and transparent depth of colour, some of these pools are like molten jewels. Blue is the most common colour, and is often very pure. But, when a shallow basin is lined with sulphur (thus having a yellow background), the colour is a very brilliant green, due in this

case, not to impurity in the water, but to the fact that, in the colours reflected by sulphur, blue is feeble, but red and green are strong, and the blue water subduing the red, we get a green residuum transmitted. But there are green pools where there is no yellow background, and the shallow parts of the blue pools are often green. From careful experiments, it appears that the substances actually dissolved in these waters do not affect their colour. The colour depends upon the mechanical state of the water and upon its depth, the blues showing when the water is fairly deep and free from foreign particles. As the water shallows, or as the suspended particles increase, it becomes greener, and a large increase of suspended matter may make it yellow. Peat gives to water a beautiful transparent brown hue. If water is really charged with mud, we see simply a liquid of the colour of the mud. The mud geysers and pools in the Yellowstone National Park afford excellent examples of coloured mud. In the Gibbon Paint Pot Basin almost every colour is represented, white, orange, green, violet, purple, blue, brown, red.

25A. *Ice.*—Compact *ice* has a colour similar to that of water. If of great purity and depth it appears practically black. In moderate thickness the light transmitted is of a rich blue tint. This is beautifully seen by looking into a glacier crevasse. Filled with air-bubbles ice is white. (Sect. 30.) The veined or ribboned structure, often visible in glacier ice, is due to alternate layers of blue and white ice; the former transparent, being free from air, the latter translucent or opaque, being interpenetrated by air-spaces. (Sect. 30.)

25B. *Sea-water.*—*Sea-water* is somewhat similar in colour to fresh water, and where deep and pure appears black. Where a river brings in mud the water looks green, and it is green near the coast, if this is of a nature to supply solid particles to the water. Over the Banks of Newfoundland the Atlantic water is shallow and green. The explanation,

as to particles in suspension, is similar to that for fresh water. When a mass of foam is viewed through the water, the colour is greenish-blue or green, the foam forming a reflecting background. Waves enhance the effect by acting as cylindrical lenses. The greenness of shallow water will be increased by a floor of yellow sand. (See remarks on geyser-pools and sulphur.)

It should be carefully borne in mind that *very small* particles in water may act by selective reflection, a phenomenon quite different from the selective absorption with which we have been dealing. (Sect. 46.) M. Soret maintains that the deep blue colour of the Lake of Geneva is due to very small suspended particles, and is therefore similar in its character to that of the sky. He found that the light from the interior of the lake was polarised like that of the sky.

We must carefully distinguish the colour proper to water from the reflection-colour seen on its surface. This latter colour is of course the same as that of the objects (the sky, mountains, etc.) which are reflected. A pool of brown water under a blue sky will appear blue, if only the surface reflection is visible.

Prof. Tyndall, in a voyage to Algeria, carefully investigated the colour of sea-water, noting the colour seen at any particular place, and at the same time securing for subsequent examination a specimen of the water. I give here some of his observations. Three specimens of water were respectively green, clear green, and bright green, and corresponding to these tints it was found that the first was thick with fine particles, the second thick with very fine particles, the third still thick, but less so than the second. So it will be seen that the green brightened as the amount of suspended matter diminished. Near Gibraltar the water of the Atlantic current was deep indigo blue, whilst only a few yards away the sea was green. On examination it was found that the deep blue water was almost free from suspended particles, but that the green water contained many. Further on the water was cobalt-blue, and was again pure, but not so pure

as when of the indigo colour. Near Cadiz the water was yellowish-green, and was thick with suspended matter. Fourteen miles away the yellow-green changes to emerald, and the quantity of suspended matter diminishes. Approaching some rocks the water is strongly green, and the amount of diffused material increases. In the Bay of Biscay the water becomes indigo coloured and is nearly pure. Near the Isle of Wight the colour was yellow-green, and the water was thick with suspended matter. All these results are explainable by the fact that water absorbs first the red, and then the other colours in order, the particles furnishing the reflecting background.

Local sea colour, due to muddy impurity, has not escaped Tennyson :

> "Men saw the goodly hills of Somerset,
> "And white sails flying on the *yellow sea.*"

In the Island of Capri, near Naples, is the Blue Grotto—a lofty cave, with a very low entrance. The result of this arrangement is to shut out direct light, so that the interior is practically illuminated only by the bluish light which has been reflected from the interior of the sea overarched by the Grotto. If a diver descends into the water, his body presents a blue appearance, whilst any adherent air-bubbles gleam like silver, owing to total internal reflection.

26. *Colour of Gases and Vapours.*—Gases and vapours may be coloured. Chloriné gas is yellowish-green because it absorbs the blue rays. Iodine vapour is purple because it stops out green. Many gases have very definite absorptive powers for certain portions of the spectrum ; and indeed, it is this definiteness which is the foundation of spectrum analysis. Nitrogen tetroxide—a brownish red vapour—shows a remarkable set of absorption bands in its spectrum, the bands being especially marked in the blue and violet. The colours due to the atmosphere, to fogs, clouds, etc. (media not in themselves coloured), will be best considered in connection with the colours due to reflection from small particles. (Sect. 46.)

It has been stated by more than one observer that the sun has been seen of a vivid green colour when viewed through escaping steam. In May 1888, in company with some friends, I visited a Monmouthshire Colliery for the purpose of investigating this statement. We made careful and prolonged observations of the appearance of the sun seen through steam escaping at various pressures. We also shifted our point of view so as to see the sun through different portions of the vapour. In no case could we see any colour, but orange or red (Sects. 46 & 47), that could be attributed to the action of the steam. In a few cases the sun looked greenish, but the colour was due to the excitement of the eye by the extremely bright light, and to the variations of intensity introduced by the intervening vapour, which varied in its course and density. When the sun, viewed through the steam, appeared greenish, the colour remained on moving so that the sun was seen without any intervening vapour. Also, I could not get the green, when viewing in a piece of plain glass the sun's image through steam, because (I suppose) the intensity of the light was too feeble to irritate the retina and so give rise to subjective phenomena. My opinion is that the green is a subjective phenomenon (due to retinal irritation) and that it should be classed with the phenomena referred to in Sect. 187. I should however be glad of further evidence on the point.

27. *The Green of Vegetation.*—The green of vegetation—due to chlorophyll—presents several interesting peculiarities. Chlorophyll is dichroic, being green in small thickness, and red when a great depth is looked through. (For its spectrum see Section 17A.) In sunlight a solution of chlorophyll exhibits a beautiful blood-red fluorescence. (Section 67.) From most green pigments, red is absent ; but, in chlorophyll the extreme red is present, and this fact causes leaves to assume an orange tint at sunset. (Sect. 56.) (For the spectrum of the light reflected from a green leaf, see Plate II.)

Viewed through a peculiar combination of coloured glasses—called an Erythroscope—the grass looks coral-red, the sky greenish-blue, and a cloud purple-violet, the landscape appearing as if changed by an enchanter's wand. The combination should be one capable of transmitting the extreme red, greenish-yellow, green, marine, and blue, and shutting off the orange, yellow, and violet. A cobalt glass and a deep yellow glass will do. Through a blue glass the landscape has a wintry aspect, through a yellow one a summery appearance; for the yellow glass brings together the warm colours, excluding the colder ones, whilst the blue glass does the opposite. A neutral-tinted glass subdues the colours, but leaves them relatively unaltered. (See Sect. 22A. For foliage tints, etc., see Sections 306 and 308.)

28. From some recent investigations, it appears that the rays, most effective in promoting the decomposition of carbonic acid, by plants, are the red rays between the lines B and C, and these are the very rays which are most powerfully absorbed by chlorophyll; the dark band seen in the absorption spectrum of that substance being due to their absence. The beautiful and varied colours displayed by flowers are seen by internal reflection after absorption. (Sect. 30.)

"C."

29. *Colour due to absorption, and seen by internal reflection.*—We now reach the commonest case of all, that of an ordinary coloured body, such as a pigment. Let white light fall upon a coloured powder, a piece of coloured wool, etc. One part of the incident white light is reflected unchanged from the surface, and dilutes the colour of the second part. This part penetrates more or less deeply into the substance, experiences reflections, more or less irregular, then emerges and reaches the eye. During the passage of the light into and out of the substance selective absorption occurs, and the emergent light is consequently coloured. To get colour in this way, the body must in some degree be

transparent, that is to say, the light must be able to penetrate some thickness of it, however small such thickness may be, and probably no substance is absolutely opaque, when made very thin. The more opaque the substance, the smaller the depth to which the light can penetrate below its surface. The change of colour takes place, not in the act of reflection, but by reason of the absorption; the reflection is required to send the light back to the eye, the absorption to colour the light. A yellow powder appears yellow, because the white light, falling upon it, is robbed of its more refrangible rays (the blue and violet), in passing into and out of a small depth of the powder, so that the emergent reflected light is yellow. Powdered indigo appears blue because it absorbs yellow. The action is subtractive not additive. A semi-transparent substance may appear by the light it reflects of the same colour as it does by that it transmits.

30. *Colour of powders, flowers, foam, &c. Irregular reflection.*—Crush a piece of colourless transparent glass, and we get a white powder. The powder is optically discontinuous, each particle being separated by air from its neighbours. Innumerable irregular reflections occur at the limiting surfaces; these send back light to the eye, and, the individual fragments being uncoloured, there is no selective absorption, so that the powder, in white light, appears white. A lily appears white for a precisely similar reason, the little cells representing the glass fragments. In a poppy petal, or in a green leaf, irregular reflection occurs just as in the lily, but, the cells being filled with a *coloured* juice, selective absorption takes place, and the emergent light is coloured red or green. Foam, that is water and air, is in its action on light analogous to pounded glass, and looks white when the water is colourless, and coloured when the water is coloured. A dense cloud, which may appear black, when between the eye and the sun, becomes brilliantly white when so placed as to reflect the light. A cloud, like foam, is an irregular mixture of water and air. The individual particles

of ice which form snow are transparent, but the optical discontinuity, due to the intervening spaces of air, causes irregular reflection, and the snow appears white like pounded glass. So also ice is white when it is not compact but is filled with air-bubbles. (Sect. 25A.) Wool, cotton, etc., are so made of fibres and cells that the incident light is irregularly reflected, and emerges, after selective absorption, coloured by the colour with which the substance happens to be dyed. By oiling a piece of ordinary white paper its irregular reflect ing power is much diminished. The paper becomes grayer or darker, and, at the same time, less opaque or more translucent. Tracing paper is a good example.

The colour of a perfectly transparent (optically homogeneous) solid, or liquid, cannot be seen, unless there is placed, either within or without it, a reflecting body: e.g. chalk in a liquid, or paper behind a stained glass. A blue liquid against a black background looks colourless; but, put chalk particles in the liquid, and we see its colour at once, the light being coloured in passing through the liquid to the chalk, and then again in passing out, after reflection from the chalk. The chalk reflects the light, the liquid colours it by absorption. As the spectral colours are simple, it follows that if a coloured object be held in a portion of the spectrum, it will appear of the same colour as the incident rays, if it is able to reflect them; if not, it will appear dingy or black; for example, red wool is red in the spectral red, but black in the spectral green. If the incident light be compound, but not white, the coloured object will appear of the hue of that constituent (or of those constituents) of the compound which it is able to reflect.

31. *Colours of mixed powders.*—If two differently coloured powders are mixed, we get a result similar to that we got when two stained glasses were placed one behind the other. (Sect. 22.) A yellow and a blue powder mixed look green. (For example, artificial ultramarine and chrome-yellow.) The white light, passing into and out of

the powders, is twice sifted, undergoing two selective absorptions, and emerges robbed of all except green, the only colour (the residual light) which passes through *both* powders. The green is usually sombre in tone, for it represents but a small part of the total incident light. Prussian-blue and gamboge-yellow produce a brighter green than true ultramarine-blue and cadmium-yellow, because the former pair are more transparent to green than the latter. Ultramarine and vermilion powders mixed produce a poor dark gray purple, for each is nearly opaque to the light transmitted by the other. Vermilion and emerald green powders mixed produce a dull sort of brown. This I think results from the green allowing a little red to pass through, whilst the red probably allows none of the green to pass through, so a subdued red—a brown—is seen, partially modified by the surface layer of red and green, which will add a little orange by mixing by adjacency. (Sect. 80.)

32. *Coarse and fine powders.*—A substance in coarse powder is deeper in colour than is the same substance in fine powder, because the light has to penetrate deeper, and thus suffers a greater absorption, before it is reflected. Also the quantity of light reflected depends upon the number of reflections, so that with large particles the number of reflections is fewer.

33. *Impurity of the colours of ordinary objects. Surface-reflection of white light.*—The colours reflected from ordinary substances are very far from being optically pure. Not only is coloured light (unless it is specially obtained from a pure spectrum) usually composed of rays of several different wave-lengths (yellow for example containing yellow red and green), but there is a greater or less amount of *surface* reflection of unaltered incident light, which is therefore white when this light is white. This white light mingles with dilutes and makes impure the reflected coloured light. Viewed through a spectroscope, vermilion in powder reflects

red nearly as strongly as white paper does, whilst the other colours of the spectrum—due to surface reflection of white light—are more feebly represented. So also in the spectrum from emerald-green we see a bright green (but not so bright as that from white paper), and on either side of it the other colours of the spectrum more feebly represented. Chrome-yellow reflects brilliantly red yellow and green, and the other colours much more feebly. Powdered artificial ultramarine reflects blue and violet almost as brightly as white paper, but other colours are darkened. Paper, painted with cobalt blue, reflects all the colours, but the red yellow and green are relatively more darkened than the blue and violet. (Plate II.) If the luminosity of white paper be taken as 100, the luminosities of vermilion, emerald-green, and chrome-yellow, are about 25, 48, and 75, respectively. A painted surface evidently can never be so bright as a white one. The most that can be expected is that it should reflect its own peculiar colour as strongly as a white one would do. The very cause of the surface appearing coloured is that it does not reflect all colours equally well. (Sect. 70.)

34. *The surface layer.*—The colour of a mixture of two powders is influenced also by the fact that the superficial layer of particles presents a mosaic. The colours of this mosaic mingle by adjacency; and, if they are yellow and blue, the resultant tint is gray. So the emergent green light is modified, not only by an actual surface reflection of white light, but also by a gray produced as just stated. This gray light like the white light is diminished greatly by mixing the powders with oil.

35. *Rough and smooth surfaces.*—Rough surfaces scatter or reflect light irregularly, smooth ones regularly. Compare a glass plate with glass powder. A stick of red sealing wax shows in certain positions a white bar of reflected light, whilst in others we see its true red colour. Polished silver and chalk are good examples of regular and irregular reflection respectively. If a plate of coloured glass be held in an

inclined position over white paper we see the blue colour of the glass; if we now take another piece of white paper, and let its image, reflected from the glass surface, also fall on the eye, the original colour will appear diluted and impure.

36. *Change of Medium. Chalk, Water-colours, Oil-paints.*—If water, and still more if oil, be added to a powder, its colour is enriched and deepened, for the surface irregular reflections of white light are weakened, the optical discontinuity being much lessened owing to the refractive power of water and oil being much greater than that of air. The medium therefore with which pigments are mixed is of importance. In coloured chalk and oil-paint we have the two extremes, water-colour being intermediate. The fact that pigments are deeper when moist than when dry is a difficulty especially in fresco and water-colour painting, and makes these processes less easy than ordinary oil-painting; in which also the thickness of pigment is considerable, and there is no white background. The spectrum of vermilion under water has its green and blue portions darker than they are in the spectrum of the dry powder, whilst under oil the blue disappears and the green is very dark. To further lessen irregular surface reflection paintings are varnished with some transparent medium. The surface reflection being now a regular one, we can easily place ourselves so as not to receive the glare of it, when looking at a picture. The varnished colours look darker than before. Water-colours are more or less transparent, and are laid in thin washes over white paper. Each wash adds to the absorptive effect, and destroys some of the originally white light reflected from the paper. Great care is needed in superposing washes of the same colour. A thin wash of carmine is pink, a thick wash is much darker and tends to scarlet. (Sects. 21, 204.) Still more care is necessary in superposing washes of different colours, for every layer both darkens and changes the preceding hue. The explanation of the result is similar to that given with regard to coloured glasses. (Sect. 22.)

Blue wash over yellow gives a sombre green, blue wash over red a sombre purple, if the blue transmits some red. The application of a transparent pigment to a painted surface is called glazing, and produces rich effects. In scumbling, a thin film of a nearly opaque pigment is laid over other colours, and conveys an idea of distance or mystery.

37. *Influence of Form and Texture.*—The form and texture of a substance may do much to enrich and purify its colour, if they are such as to cause repeated reflections. The superficial reflection is tinged and the internal reflection deepened by the repetition of the process of absorption. Hence the depth of colour seen in velvet and wool, and in the cups of flowers. In silk the fibres can be placed parallel to each other, so that the surface reflection of white light is definitely directed, and the fabric exhibits, either a rich saturated colour, or a pale colour, according to the position from which it is viewed. Shot silk, in which the warp and the woof are differently coloured, also exhibits most beautiful effects. In velvet almost all surface reflection is quenched owing to the fibres being placed end on to the surface. Silk velvet is much freer than cotton velvet from surface light. To imitate texture the artist resorts to various devices (scumbling, glazing, hatching, etc.) and often succeeds to a wonderful extent.

38. *Lustre.*—Lustre is the name usually applied to the appearance of reflection of a more or less metallic brilliancy seen through a transparent or translucent medium. Metals are often coated with transparent coloured lacquers, or are chemically treated, so as to alter the colour of the surface. Avanturine is glass crowded with crystals of copper. Lustred ware owes its hue to fine films of metals reduced by the firing. Chatoyant stones, such as moonstone, cat's eye, crocidolite, owe their peculiarities to internal structure. The following terms are used in describing the lustre of gems, metallic, adamantine, resinous, vitreous, waxy, pearly, and silky.

Enamels consist of various kinds of translucent glass coloured by metallic oxides. When a metallic surface is enamelled, the light passes through the enamel to the metal. This reflects the light, so that it passes a second time through the film, and is thus richly coloured by the absorption produced in the double transmission.

For further remarks on Lustre see Sects. 107-9.

39. *Minerals, marbles, stones, wood.*—There are many richly tinted minerals, such as lapis lazuli, malachite, etc. Agates, marbles, and various stones, are greatly prized for their colour and structure. The surface can be polished to better bring out the peculiarities of the substance. Woods are usually subdued but varied in colour, and their texture and lustre (when polished) add greatly to their beauty. The medullary rays, or silver grain, the annual rings, the fibrous structure, etc., all produce their effect. (Sects. 313, A, B, C.)

40. *Coal-tar Dyes.*—The Coal-tar dyes constitute an immense series of colouring matters. The hues they possess are usually highly saturated and bright, and this fact makes them difficult to manage artistically. Dyes have been produced corresponding to every colour of the spectrum, and also to purple, a colour absent from the spectrum.

41. *Colour and molecular structure.*—We see an object, not by the rays it absorbs (rays which may be considered to have some intimate relation to the molecules of the object), but by the rays it rejects. A yellow body is one whose real relationship is with blue and violet, for it receives these colours from the incident white light, but renders them not again. The rays absorbed are complementary to those reflected. (Sect. 128.) Attempts have been made to account for the colours of objects by means of their molecular and chemical structure, and the carbon compounds especially appear to offer a promising field for researches on the connection between colour and molecular structure. But the subject is as yet in its infancy, and would involve a systematic study of absorption spectra, to clear it up.

"D."

42. *Colour due to selective surface-reflection.*—Surface-reflection is, in the case of most substances, general, not selective, that is to say, the incident light is reflected unchanged in colour. This kind of reflection, being well typified by glass, may be called *vitreous.* (The colour of the glass is immaterial.) The surface-reflection from polished marble, varnished wood, water, etc., is of the vitreous type. The light, that even a black surface reflects, is white; and were the moon sheathed in black velvet she would still—as Tyndall says—appear to us, as if—

"Clothed in white samite, mystic wonderful."

43. *Metallic, or selective reflection. Metals.*—But there is another sort of surface-reflection (met with only in solids), and well exemplified by many metals and other substances. By this kind of reflection, which may be called "*metallic,*" the reflected light may be strongly coloured by a preferential selection (in the act of reflection) of certain colours out of the total present in the incident white light. The reflection colours of gold and of copper are produced in this way, and not by transmission accompanied by absorption, as is the case with coloured glass or powders. The colour transmitted is indeed entirely different from the coloured reflected light.

If gold be taken, thin enough to be translucent, we find that it still reflects a yellow coloured light, whilst it transmits a bluish-green coloured light. This bluish-green is the colour due to selective absorption, and is doubtless somewhat modified by the selective reflection cutting off some of the yellow. Tested by the spectroscope, gold leaf reflects all the spectral colours, but the yellow with especial brilliancy. It dulls all the transmitted colours, and cuts off the violet and the outer red, letting through the inner red, the yellow, green, and blue, but reducing the intensity of the red and yellow relatively to that of the green and blue. Gold, in a very finely divided state, suspended in a solution,

transmits a blue coloured light. Similarly, a thin film of copper reflects reddish orange, transmits blue, and absorbs yellow.

44. *Non-metallic bodies.*—Many non-metallic bodies also have the power of selective reflection. The bronzy-looking crystals of potassium permanganate possess the power of metallic reflection for green, but the power of only vitreous reflection for red and blue. A solution of this salt powerfully absorbs the very same green rays which the solid salt so copiously reflects. If the solution of the salt be weak, the green part of the spectrum is crossed by a series of dark bands, and careful spectroscopic observation of the light (reflected from a crystal) shows it to consist of a series of bright bands, exactly coincident in position with these dark bands. These bright bands are separated by spaces in which the reflection is vitreous, so that there is a rapid interchange of vitreous and metallic reflection within very narrow limits. Under the polariser the light reflected from the crystals is a purer green, being freed from the vitreously reflected light. A film of the aniline dye—magenta—appears rosy by transmitted light, but bronze-green by reflected light. But this bronze-green is not the true colour of the metallically reflected light, for the light vitreously reflected is present as well. By a Nicol prism, however, we can quench this second plane-polarised part of the light, and the metallically reflected elliptically polarised light is then seen to be peacock-blue, and this is the colour, which a solution of the substance absorbs.

If there is no absorption, the reflected and transmitted colours, combined, will reproduce the original white light. With the spectroscope it was found that this particular aniline film transmits the outer red and violet, and reflects all colours but these. Powdery indigo is of a deep blue colour by reflected light, and when thin enough it transmits the same blue light. (Sect. 29.) But, when burnished, its surface has the property of reflecting metallically a coppery

light. In crystalline powder, indigo exhibits a colour compounded of the transmitted blue and reflected coppery light. Magnesium platinocyanide, murexide, etc., also possess the property of selective surface-reflection. Iron pyrites, of which a crystal exhibits a brass-yellow colour, is grayish blue when reduced to fine powder. (Prof. Church.)

It will be seen that this peculiar kind of reflection of certain colours is associated with a quasi-metallic opacity as regards the transmission of the same colours.

The splendid hues of some birds and insects appear also, in part at least, to be due to metallic reflection. The colours in a peacock's feather change with the angle of view, and are also modified when viewed through a polarising prism. (See, however, Sect. 63A.)

45. *Colours of metals.*—Metals reflect light very copiously, silver as much as 92 per cent. of the incident light, whilst white paper reflects only about 40 per cent. By repeated reflections it is easy to intensify that colour which the metal most copiously reflects: there is less light, but the hue is purer. The rich colour of a gilt cup is due to repeated reflections. The angle, at which a metallic surface is viewed, modifies the colour of the reflected light, the proper colour being more conspicuous the smaller the angle (measured from the normal) of reflection. Very rich colour effects are produced by grooving or chasing the surface so as to give repeated reflections at small angles. The colour of a pure metal may be greatly modified by alloying it, even slightly, with another. Gold is made greenish by silver, reddish by copper, orange-yellow by a mixture of both. Copper, alloyed with about 5 per cent. of aluminum, resembles gold. The reflection colours of some common metals may here be given; copper red, gold orange, lead bluish-gray, silver orange-yellow, steel neutral gray, tin grayish-yellow, zinc bluish-white. The metallic lustre of gold prevents it disturbing the harmony of colours in the way that a yellow pigment might do, and

the fact that it is bright and "advancing" adapts it well for frames, as we seem to see the picture through and beyond the frame.

"E."

46. *Colour due to selective reflection from small particles.* —When small particles of any kind are diffused through any transparent medium we observe the phenomena of Opalescence, or Interior Diffusion. Provided the particles are small enough, their own colour or character makes no difference. Finely divided sulphur, carbon, water, and milk, all produce the same result. Opalescence is due to the small particles scattering the short waves of light more copiously than the long ones. When the particles are extremely small the reflected light is deep blue; this becomes paler as the particles increase in size, and are so enabled to reflect the longer waves, until, at last, all waves are reflected, and the light is white. It is interesting to note that the light reflected laterally from very small particles, that is at right angles to the rays, is completely polarised.

It will be understood that these phenomena of small particles have nothing in common with those described in Sect. 42. (Selective surface-reflection.) The phenomena now treated of really depend upon the fact that the ratio of the average diameter of the particles is comparable with the length of a wave of light. The phenomena are in this respect related to those of diffraction. (Sect. 62.)

47. *Turbid Media.*—The correlative effect to this reflection of blue and violet is the transmission of orange and red. A turbid medium looked at is blue, looked through is orange. Water containing soap milk or mastic in suspension shews these results very well. The water of the Opal Spring, in the Yellowstone National Park, is orange by transmitted, bluish by reflected, light. Lord Rayleigh, by mathematical investigation, has shown that the power of very small particles to scatter rays varies as the inverse fourth power of the wave-length. In a given case it can be shown

that a certain red will be transmitted about thrice as freely as a certain blue. When very fine particles are suspended in a coloured medium I suppose we should still get selective reflection, but modified by the selective absorption of the medium; this should be borne in mind in connection with the remarks made in Sect. 25.

The explosive combination of chlorine and hydrogen is brought about by the shorter waves. That mere traces of finely divided particles will cut off these waves is shown by the fact that water (rendered just perceptibly opalescent by one-tenth of a grain of sulphur to the gallon) will so alter the light transmitted through it, that the combination does not occur.

48. *Milk, Opalescence, Pigments in fine particles.*—"Sky-blue" milk owes its reflected colour to its diluted condition. It is said that blue eyes owe their colour to turbidity. Glass is made opalescent by diffusing through it small particles of oxide of tin, etc. Such glass is reddish by transmitted, bluish by reflected, light. Opals are full of minute fissures—air-particles—reflection from which is probably one cause of their splendid colours, though diffraction no doubt plays also a large part. The bluish cast of many gray pigments (made by adding black to white) is also traceable to interior diffusion. A mixture of white lead with burnt cork has been called "beggars' ultramarine."

[A little ivory black thinly rubbed over a white surface appears brownish, for we are viewing a white background through a black turbid medium, which scatters the blue and violet rays in addition to its general absorptive action. The same black, mixed with white, appears neutral gray, and this gray thinly brushed over a black ground appears bluish by selective reflection of the shorter waves. So yellow ochre, thinly spread over white, will look orange; but, spread in a similar way over black, it will appear olive-green. Pigments appear warmer when laid thinly over a white ground, and colder when laid thinly over a dark ground. Warm and cold, as applied to colours, mean nearer the red and nearer the violet ends of the spectrum respectively.—*J. Collier.*]

But some authorities think that, as the rotation-mixture of black and yellow also gives an olive-green, and, as the rotation-mixture of gray and black is (according to some authorities) a gray tinged with blue, there would appear to be some cause, other than, or in addition to, selective reflection from small particles, if these results are to be explained; for this cause can have no place when colours are mingled by rotation. The cause suggested is that, with a feeble white light, the violet nerves are relatively more stimulated than the red, and that, with a bright light, the reverse is the case. The point is one still needing further investigation. (Sects. 195, 203.)

49. *The Sky.*—The sky owes its blue colour to selective reflection from small particles, and not to the air being a blue medium. The light reflected from the sky differs from the incident light by being relatively poorer in the long (red) waves, and richer in the short (blue) waves. Comparing the spectrum of the blue sky with that of a white cloud, Lord Rayleigh found that there is, in the former spectrum, no *peculiar* deficiency at the red end, but a general falling off as the refrangibility diminishes from one end of the spectrum to the other. There is of course plenty of light of all colours in the blue light from the sky, but the less refrangible rays are relatively deficient.

We see the blue reflected light of the sky against the dark background of space. Above the high Alps, where the particles are smaller, the sky appears of a deep blackish blue, very different from our English gray-blue, and producing different effects on the landscape. From a balloon the sky is seen to increase in blueness as the balloon ascends. Prof. Langley, in experiments, made on Mount Whitney (12,000 feet high), found that there was a greatly increased transmission of the more refrangible rays as we ascend. He draws the conclusion, that, to a person outside the atmosphere, the sun would look *bluish*, or even *blue*.

50. *Lunar Eclipse.*—The dull coppery-red colour of the disc of the eclipsed moon is well known. It appears to be

due to sunlight which has passed through the earth's atmosphere and is refracted into the shadow. In passing through the atmosphere the sunlight is robbed of its blue rays. In some eclipses this red colour is not seen, the disc being ashen gray. In all probability the cause of these variations is to be found in the condition of the atmosphere at the time of the eclipse. The ruddy tint, seen on the moon in eclipse, is much deeper than that of sunset, because the light traverses in the former case twice as great a thickness of atmosphere.

51. A sunbeam, let into a darkened room, reveals itself by lighting up the motes of dust in its path. In the open air, we have dust, smoke, fogs, and clouds, and almost invisible vapour. It has been supposed that the air molecules themselves may be really the cause of the blue of the upper regions, by acting as turbid particles in the luminiferous ether. The wonderful colours of the sunsets, seen after the eruption of Krakatoa in 1883, have been attributed, with great probability, to the finely divided volcanic dust, projected into the upper atmosphere by the enormous force of the explosion of the volcano. Viewed through a turbid medium the sun appears yellow orange scarlet and finally crimson, as the thickness of the medium traversed is increased. The blue light is scattered by reflection, and what escapes reflection is absorbed, so that there is a continually increasing proportion of the longer waves.

"It is the low sun makes the colour."

The receding line of lamps in a long street exhibits the same progressive change of hue.

52. *Fog, Smoke, Sandstorm.*—Seen through a fog, the sun, even at noon, appears red. But as the particles grow in size the differential action decreases, both transmitted and reflected light remain white, and the sun presents merely a dimmed white. Probably the presence of carbon particles (smoke) adds largely to the differential effect, and so increases the red colour. Lampblack upon glass cuts off

the violet and blue, and makes the light transmitted look reddish. Through escaping steam the sun appears orange or red, and the steam looked at is of a dark grayish blue. (Sect. 26.) In a sandstorm in the Californian Desert, I noticed particularly that the sun, though dimmed, was not reddened, the sand-grains being too large to act selectively or differentially.

53. *Dark and light background.*—As the *blue* tints are seen by reflection, a *dark* background is the best for them, whilst a *bright* background is needed to bring out the *red* tints due to transmission. These facts may often be seen beautifully exemplified by watching the smoke ascending from a Swiss cottage. Against the dark background of the pine-wood the smoke looks blue, but higher up, against a bright surface of snow, it appears brown. The smoke from a cigar excellently illustrates similar phenomena.

54. *Landscape Colours.*—The shadowed parts of a distant mountain appear filled with a deep blue haze, quite overpowering the feeble reflected light of the mountain itself. There is in fact between the observer and the mountain a piece of sky, scattering by reflection a bluish light, well seen against the dark background. The light diffused in this way is one reason for the statement, often made by painters, that there is no black in Nature. Brighten the background and the effect is diminished or lost ; and we may see the orange tint, due to transmission, if we look up through the haze at a sun-smitten snow peak, or at those parts of the mountain which are brightly lighted.

Aërial perspective treats of the effect of distance on colours, just as ordinary perspective treats of the effect of distance on forms. Aërial perspective is in fact the artist's term for the peculiar effect due to the illuminated masses of air between the observer and distant objects. A large amount of vapour makes objects look large and distant, a small amount makes them look small and near. (Sect. 324B.)

There is a natural tendency to represent a distant object, not in the colours that it actually sends to the eye, but in the colours we know it has when quite close to us. Hence it is of great importance to study the influence of aërial perspective, which profoundly modifies the colours of far-off objects, making, for example, a greenfield bluish-gray. (Sect. 309.) Shadows and dark objects tend to become bluer and lighter, but bright ones are either unchanged or become warmer in tint. The colour then of a distant object is modified in two opposite directions. The light coming from it is more or less robbed of its blue rays by the intervening atmosphere; but then this atmosphere itself sends a bluish light to the eye. If then the distant object is a very bright one, the effect of its own altered light will preponderate, and it will appear redder. If, on the other hand, the light from the atmosphere is the stronger (as when the background is dark) we get the blue light from this medium preponderating. When the two effects are balanced, the colour of the object will be unaltered. If there be parallel ranges of mountains, the various chains are better distinguished at sunset than at noon. The bright background of sky brings out the profiles, and the illuminated interposed air enables us to distinguish chain from chain.

55. *Rood on Landscape.*—[In a distant mountain not many details will be visible, and the actual local colours scarcely appear, blended as they are with soft tints of the sky medium. The contrast between light and shade is greatly lessened, the general luminosity of the mountain being very high, and its hues partaking in character of those of the sky. As we approach the mountain the atmospheric effects naturally diminish. In the sunlit portions, delicate greens and soft varied grays appear, while the shadows lose their heavenly blue and, darkening, become bluish-gray. Continuing to approach, the local tints of the lighted portions appear clearer and clearer, and the coloured light from the shadows begins to make itself felt, and, mingling with the blue reflected light, produces soft purple and green grays, and other nameless tints.]

If we again recede to our former position, we shall notice that, as the sun sinks, the sifting process is more complete, the shadows become bluer, the lighted parts redder.

56. *Rood on Sunset.*—[When the sun is low its rays traverse thick layers of the atmosphere, and wonderful chromatic effects result. Near the sun the light is yellowish, but too bright for its colour to be clearly seen; further away the colour deepens into orange and red; and still further fades out into purplish-gray and grayish-blue, finally passing into sky-blue. The warm tints are produced mainly by transmitted, the cold by reflected, light, and the neutral hues by a combination of both. As the sun sinks lower, and its light traverses a greater mass of suspended particles, the warm tints gain the predominance. In clear sunsets there is above the sun a regular transition from the transmitted to the reflected colours. The landscape sympathizes with the sky, the green of vegetation becoming orange-tinted. (Sect. 27.) Clouds break up the symmetry of the sunset sky, giving rise to the most magnificent colour effects known.]

Nature's grand transformation scene is there.

> "This majestical roof fretted with golden fire—a foul
> And pestilent congregation of vapours."

The series of sunset hues is, by Prof. Rood, given as follows: yellow, orange, red, purple, violet-blue, gray-blue. These colours may vary much in tone, tint, and hue. I suppose yellow is seen when the sun is still very bright, but has lost some of the blue rays; then, as the blue and green are lost, we should get orange; and, continuing the absorption, red. Purple would be due to red transmitted light and blue reflected light mingling together. A blue cloud is impossible, for the sun's light, by which the cloud is seen, is never blue within our atmosphere; and the vapour, which is fine enough to reflect only blue light (out of the white sunlight) is too fine to take bodily shape as a substantial cloud; the sky, in fact, is our "blue cloud."

57. *Green in the Sky.*—A green *cloud* is, I believe, never seen, for vapour particles, which would reflect green, would also be large enough to reflect blue, and, as the particles grew larger, yellow would be added, until at last all colours were reflected, and the light would be white. Selective reflection from small particles can *isolate* only the blue rays; but when to these are added green, a bluish green may be producible. Certainly I should add bluish green to the tints sometimes seen in the sky after sunset. I have noted the succession orange, blue-green, blue, and violet-blue, as we ascend from the horizon. This green, or bluish green, should be carefully distinguished from a vivid green shown under other circumstances, as for instance, when the sky is seen through openings in bright red clouds. In this case the green is due to contrast-illusion; it is a complementary evoked by the red. (Sect. 211.) The moon in a red sky may look unmistakably green. (Sect. 213.)

The blue and violet shadows of trees, etc., often noticeable at sunset, are due mainly to contrast, being especially developed when the sky is yellow or orange, so that we see a shadow upon a coloured ground. (Sect. 224.)

58. *Mont Blanc and Norway.*—Some years ago, on the Flégère, I recorded the following sunset tints seen upon Mont Blanc. Bright yellow, then orange, and lastly faint pink. During early sunrise at Chamouni, Mont Blanc appeared flushed with pink, which changed to orange. The Aiguille du Gouté was reddish, and the south end of the valley of a brown-orange tint.

In a voyage to the North Cape (1882), the following notes were taken. The sunlight falling now on snowfield, now on rock, now on verdurous soil, gives rise to a great variety of tints, each of which, as the sunset deepens, changes in its own way. The rugged hills of the mainland are rose-purple. The Kunnen promontory is green from the pine-woods which clothe it. The water is pale brown, with a play of blue (probably a subjective complementary

tint) along the slope of each silver-edged ripple. The isles seaward are purple, varying from plum-colour in those that are near to pale-violet in those that are far off. The very slow sunset, the prolonged twilight, the splendour and lingering loveliness, can be seen only in high latitudes. For those who cannot visit Norway the western coast of Scotland will provide examples, almost unsurpassed, of sea sky and mountain colour.

As a contrast to a slow sunset over the North Sea, I may perhaps instance a rapid sunset seen in Kansas. Here the great green prairie, which like an ocean rolls away on all sides to the horizon, warmed up into orange as the sun reddened to its fall.

59. *Colorado Cañon, etc.*—I here quote Captain Dutton's eloquent description of a sunset seen over the grand Cañon of the Colorado of the West (U.S.A.) [The haze relaxing its steely glare has changed to a veil of transparent blue. Vast alcoves are disclosed, illumined with Rembrandt lights, tinged with the pale refined blue of the ever-present haze. The western sky is all aflame. The scattered banks of cloud and wavy cirrhus have caught the waning splendour, and shine with orange and crimson. Broad slant beams of yellow light, shot through the glory-rifts, fall on turret and tower, on pinnacled crest and winding ledge. The summit band is brilliant yellow, the next pale rose. But the grand expanse within is deep luminous resplendent red. The blaze of sunlight, poured over an illimitable surface of glowing red, is flung back into the gulf, and, commingling with the blue haze, turns into a sea of purple of most imperial hue—so rich, so strong, so pure, that it makes the heart ache and the throat tighten. It is in these kingly colours that the highest glory of the Grand Cañon is revealed.]

The grand painted Cañon of the Yellowstone at sunset, and the Crater of Vesuvius, are the finest examples I have seen of rich and varied natural colour. The naturally

brilliant hues of the rocks, which in both places are volcanic and stained with iron, sulphur, etc., are enriched by the reddened sun. The strata in the Garden of the Gods, near Manitou (Colorado State), are vivid red white and yellow, and produce brilliant effects by day, and very weird ones under the moonlight.

60. *Atmospheric transparency, etc.*—When the vapour particles are enlarging, and so really clearing the haze, distant hills look close, and we may prophesy that rain is at hand, for the growing water-spheres will soon be large enough to fall. On the other hand, in places, where the air is intensely dry, distant mountains are clear, and are so singularly well defined, that they seem near at hand, ten miles looking less than three. The dark parts, owing to the absence of vapour, are in almost unrelieved shadow. I saw remarkably good examples of the effects just described when crossing the Mohave Desert (California, east of the Sierra Nevada) in 1883.

Clarence King thus describes the same neighbourhood. [An unmistakable purity and delicacy of tint, with transparent air and paleness of tone, give all desert scenes the aspect of water-colour drawings. I could see the gradual change from rich warm hues of rocky slope, or plain overspread with ripened vegetation, out to the high pale key of the desert.] Speaking of a view from the summit of Mount Shasta : [We were high enough to lose the ordinary landscape impression, and reach that extraordinary effect of black-and-bright topography seen upon the moon through a telescope. From every object streamed out dense sharp shadows, slowly lengthening their intense images. Afar in the north, bars of blue shadow streamed out from the peaks, tracing themselves upon rosy air. A long cone of cobalt-blue, the shadow of Shasta, fell strongly defined over the plain. As the sun sank this gigantic spectral volcano rose on the warm sky, till its darker form stood huge and terrible over the whole east.]

Mr. Lockyer has some very interesting observations upon the colours seen at the part of the sky opposite to the setting sun. The shadow of the earth—a gigantic mysterious crescent—is thrown upon the sky and slowly creeps upward. Sometimes great rifts of darkness are seen radiating in the east and west, due to clouds (above or below the horizon) intercepting the light; or, in some cases, due to a mountainous island, which may have sunk beneath the horizon.

For descriptions of sky and landscape, unsurpassable in eloquence, the reader may be referred to Ruskin's "Modern Painters."

60A. *Tyndall on the Sky, etc.*—The light from the sky being polarised, but that from clouds being unpolarised, it results that by using a Nicol prism considerable changes of appearance may be brought about in their relative appearance. Prof. Tyndall eloquently describes some remarkable changes produced in this way.

[Looking at the Weisshorn through the Nicol the glow of its protuberance was strong or weak according to the position of the prism. The summit also underwent striking changes. In one position it was pale white against a dark background; in another it was dark mauve against a light background. The air was filled with a silvery haze in which the Matterhorn almost disappeared. This haze could be wholly quenched by the Nicol, and then the mountain sprang forth with astonishing solidity and detachment from the surrounding air. When the sky was quenched the peaks of the Dom glowed as if suddenly set on fire. This was immediately dimmed by turning the Nicol through 90°. It was not the stoppage of the light of the sky behind the mountains alone, which produced this effect, the air between them and me was highly opalescent, and the quenching of this intermediate glare augmented remarkably the distinctness of the mountains. The only things changed are the sky behind and the luminous haze in front of the mountains. These are changed because the light of the sky and of the haze is plane polarised light, whilst the light from the snows and

the mountains, being sensibly unpolarised, is not affected by the Nicol. It is not the interposition of the haze as an *opaque* body that renders the mountains indistinct, but the *light* of the haze which dims and bewilders the eye, and thus weakens the definition of objects seen through it. These results have a direct bearing upon what artists call "aërial perspective." If the mountains are separated from those behind them by a thin blue haze, their relations as to distance are unmistakable. When this haze is quenched by the Nicol, aërial perspective is abolished, and mountains very differently distant appear to rise in the same vertical plane. The haze varies with the temperature and humidity of the atmosphere. It is a piece of more or less perfect sky, produced in the same manner, subject to the same laws, as the firmament itself. We live *in* the sky, not *under* it. The light of the landscape consists of two parts, the one superficially reflected is of the same colour as the incident light. The other consists of that which has entered to a certain depth and is ejected after selective absorption. This latter part gives the true colour. If, by the Nicol, the superficially reflected light is quenched, we then obtain the true colour of the grass and foliage. The hard brilliancy of the superficially reflected light being stopped, the trees and meadows exhibit a richness and softness of tint not shown under ordinary circumstances. . . . . All along the arc from the Matterhorn to Mont Blanc the light of the sky immediately above the mountains was powerfully acted upon by the Nicol. When the prism was rapidly shifted, so as to render the alternate extinction and restoration of the light immediate, the alternations of light and darkness resembled the play of sheet lightning behind the mountains. There was an element of awe connected with the suddenness with which the mighty masses changed their aspect and definition under the action of the prism.]

Prof. Tyndall has produced blue clouds, bluer than the sky, by the slow decomposition of vapours by light. Goethe's theory of Colour (Sect. 161) is based upon the action of turbid media.

"F."

61. *Colour due to Interference.*—It is a characteristic of wave-motion, that a system of waves, of a certain length and amplitude, may either double or destroy another system of similar length and amplitude. If, when white light (containing waves of all lengths) falls upon a particular part of a surface, the arrangements are such that the blue waves there destroy themselves, the result will be that that part of the surface will look yellow. Colour is thus produced by suppressing colour. The red waves (being longer than the blue ones) may destroy themselves at another part of the surface, and this second part will appear marine ; and so for each colour or wave. With monochromatic light there will be simply alternations of light (of one colour) and darkness.

62. *Diffraction.*—Light waves, passing through small apertures, or amongst small particles, experience diffraction, and the diffracted light may interfere, producing colour. The halos, round the sun or moon, are produced in this way by a cloud of particles of water or ice. Such halos may be imitated by viewing a bright point through a glass which has been breathed upon, or dusted with lycopodium powder. By looking through a feather, or through the lashes of nearly closed eyes, brilliant colours may be seen.

The Diffraction Spectrum (Sect. 10) is produced by the interference of the light waves passing through, or reflected from, a surface ruled with very fine equidistant parallel lines close together.

63. *Iridescence.*—The iridescent colours of shell and pearl are due to the interference of the light reflected from a finely striated surface. The crystalline structure of Labradorite produces a beautiful play of colours. In the opal the colours are due, in all probability, partly to interference, partly to interior diffusion.

63A. *Feathers.*—To what the colour of the feathers of birds, which show a play of colour, is due, is perhaps not settled. It may be diffraction, or selective coloured

reflection (Sect. 44), or the colours of thin plates, or a combination of these. The Touracos owe their splendid crimson to a definite pigment containing copper.

To Dr. Sorby, F.R.S., I am indebted for the following valuable notes, hitherto unpublished: [Some feathers are coloured by actual pigments, which can be extracted and used as water-colours. Others are coloured by substances similar to, if not identical with, those found in plants and flowers. Many feathers, however, like soap bubbles, owe their colour entirely to interference. These feathers give very characteristic spectra showing clearly the order of the tints, and from these we may approximately determine the thickness of the thin transparent film which gives rise to the effects. In most cases the colour is well brought out by a black background, but in certain birds, more or less closely allied to pheasants, we meet with interference colours without such black background. The foregoing two different types of feathers are easily distinguished by the facts that the pigmented feathers give the same colour in all positions, and by transmitted as well as reflected light; whereas the colour of those, coloured by interference, varies with the angle at which they are held. There are, however, some feathers, which also vary in colour with the angle at which they are held, owing to the colouring being on the top of the ribs in such a way as to change by fore-shortening.]

64. *Thin Films.*—The colours of thin films are also due to interference. Examples of these colours are presented by the soap-bubble, by an oil-film upon water, by the oxide-film produced in tempering steel, by the tarnish of copper pyrites, by ancient glass, by mica, by the scum upon a molten metal, by air in the experiment known as Newton's Rings, and so on.

The composition of any interference colour is easily ascertained by submitting it to spectrum analysis; the spectrum will be crossed by dark bands corresponding to the colours destroyed by the interference. The sum of the other colours forms the colour actually seen.

65. The twinkling colour-changes (not the fixed hues) of the stars are due to interference. The sea-mouse *(Aphrodite)* exhibits a bright play of interference colours. The brilliant colours displayed by the bodies of some insects (beetles, etc.) may be due to selective surface-reflection, or to interference, or to both combined. Besides the metallic brilliancy, often seen in colours due to interference, a brilliancy, which pigments cannot rival, it will be found that the colours change when the objects yielding them are shifted so as to alter the angle of view, and this fact much enhances their beauty.

66. *Polarisation.*—The gorgeous chromatic effects, brought about by submitting doubly-refracting bodies (crystals, strained glass, horn, etc.) to polarised light, can be produced, as a rule, only by artificial means. The colours and their combinations are often bizarre and startling. The colours are due to interference. Among the hues, produced by polarised light, are red, purple-red, purple, orange, yellow, green, blue, violet, rose, pale green, marine, tawny yellow, bluish-gray, etc.

Circularly polarised light is well fitted for experiments upon continuous change of colour. A plate of quartz, placed between two Nicol prisms, exhibits a beautiful series of continuous colour-changes, when one of the prisms is rotated. The colours seen are very much like those of the spectrum (but are not pure), and follow a similar order, but the break between red and violet is bridged by a purple.

Light may be polarised by reflection, ordinary refraction, double refraction, and scattering by small particles. (Sects. 46, 60A, 74, 76, 77.) A Nicol prism may sometimes be found useful in extinguishing the glare or reflection coming from the surface of a picture placed inconveniently in regard to light. The polarisation of the light of the sky is at a maximum along the arc of a circle everywhere 90° from the sun. Sir C. Wheatstone devised a most ingenious polar clock, in which the rotation of the plane of polarisation

with the movement of the sun, was made evident by colours developed in strips of selenite placed radially and marked with numbers for the different hours.

A plate of ice will show the colours due to the interference of polarised light, if it be held, at a proper azimuth, and so that the light, from a part of the sky 90° from the sun, passes through it, and is then reflected at the polarising angle from the surface of a pool of water. Assuming that it is water-vapour which reflects the sky light, we have water, vaporous, solid, and liquid, thus furnishing us with polariser, crystal, and analyser.

For polarised light in relation with complementary colours, see Sects. 129, 130.

66A. *Pleiochroism.*—Certain minerals exhibit the interesting phenomenon called *pleiochroism.* A crystal, straw-yellow in one direction, may be ultramarine-blue in another, though the thickness looked through remains unaltered. This peculiar action is an important factor in producing the beautiful play of colours seen in some precious stones. The diamond owes its brilliancy to its exceedingly high refractive and dispersive power, but is not pleiochroic. All pleiochroic crystals are doubly refractive. By a double-image prism two differently coloured images are seen on looking at a pleiochroic substance. The ruby and the emerald possess pleiochroism, and this peculiarity of course cannot be imitated in artificial gems. The sapphire, the topaz, the amethyst, iolite, etc., are also pleiochroic.

Pleiochroism is due to the property, possessed by doubly refracting media, of absorbing polarised rays in different proportions, according to the inclination of these rays to the axes of the crystals. Some tourmalines are green in one direction, and dark brown-red in another, though the thickness looked through may be the same in each case. (Sect. 21.) Some crystals are trichroic. The Brazilian topaz is yellowish-rose, violet, or yellowish-white, according to the direction in which the light traverses the crystal.

"G."

67. *Colour due to Fluorescence.*—Certain bodies possess the power of emitting light of a refrangibility, and therefore of a colour, different from that of the light they receive. This property is called *Fluorescence*. The emitted waves are always longer than the exciting ones, and the tint of the colour emitted is constant, if the substance be pure. If ultra-violet (invisible) rays be allowed to fall on a colourless solution of quinine sulphate, a bright blue colour is emitted. But the power of exciting fluorescence is not confined to ultra-violet rays. Uranium glass gives a yellowish-green, fraxin a bluish-green, æsculin a blue, chlorophyll (Sect. 27) a red, fluorescin a green, fluorescence. Some kinds of paraffin-oil fluoresce blue, others green; fluorspar, in different specimens, gives green, blue, or violet. The light incident on a fluorescent substance is found after transmission to have been deprived of those rays, to which the fluorescence is due. The light diffused by fluorescence, unlike that scattered from small particles, is unpolarised.

White paper itself is feebly fluorescent. According to Helmholtz, the cornea and crystalline lens of the eye exhibit fluorescence; and it is also stated that the retina is fluorescent for the violet rays. (Sect. 185.) Many substances owe their dichroism to fluorescence. The self-luminous appearance of fluorescent bodies is very strange and beautiful.

68. *Phosphorescence.*—Phosphorescence is a property closely allied to fluorescence; in fact it appears to be merely a prolonged fluorescence, which endures for a longer or shorter time after the exciting cause has been removed. The rays, which produce phosphorescence most efficiently are, like those which best produce fluorescence, rays of high refrangibility, and, in general, the refrangibility of the emitted is lower than that of the exciting light. Rubies, diamonds, the sulphides of calcium barium and strontium,

and many other substances, exhibit phosphorescence after exposure to sunlight. The range of colours produced by phosphorescence is extensive, reaching from red to violet.

Some of the most beautiful phenomena of phosphorescence are observed when certain substances are acted upon by an electric discharge in a high vacuum. Under these circumstances, diamonds exhibit a red orange yellow green or blue glow, rubies a crimson, sapphires a green. Phosphorescence is also producible in some bodies by a gentle heat. Many animals exhibit phosphorescence.

68A. *Orthochromic photography.*—The representation by photography of objects in their natural colours is still a desideratum. Something has been done towards rendering photographs more accurate in light and shade, by adding fluorescent bodies to the sensitive plate. These reduce the activity of the more refrangible rays, and so bring about a better gradation in the picture. The subject is not yet however sufficiently advanced for more to be said here.

PART III.—THE CONSTANTS OF COLOUR.

69. *The Three Constants of Colour:—Hue, Purity, Luminosity.*—The Constants of Colour are Hue, Purity, and Luminosity. The first thing that appeals to the eye in connection with any colour is its *Hue;* we endeavour to *name* the colour, as red or blue, etc. The spectrum is the best example of variation in hue. In it we have a series, which (if purple be added) is complete, and may be arranged in a circle returning on itself. (Sect. 139.) The first constant then is *Hue.*

The second constant is *Purity.* A colour is called pure, when unmixed with white light. Spectral colours are the purest colours furnished by Nature, the colours of pigments being more or less impure owing to their reflected white light. A pure colour is not necessarily bright, e.g., the violet of the spectrum. As more and more white is added a colour becomes paler and paler, and is finally undistinguishable from white. The series produced by mingling a colour with gradually increasing quantities of white may be called *Tints.* (Part IX., and also Sect. 236.) Pink is a whitish red or purple, cream a whitish yellow, and so on.

Luminosity, or *Brightness*, is the third constant of colour. It is measured by the total amount of light sent to the eye by the colour under consideration, and is independent of the hue or purity. If we gradually diminish the intensity of the light which forms a spectrum, each of the spectral hues will lessen in luminosity. (Accompanying change of

luminosity there is generally also change of hue, but this point will be considered later on. Part IX.) The series produced by increasing or diminishing the luminosity of a colour may be called *Tones*, or, if we are simply reducing the luminosity, the series of Tones is sometimes denominated *Shades*. (See Part IX., and Sect. 236.) The word *Tone* will be used to denote the absolute amount of sensation of any colour, and this depends on the luminosity, on the total quantity of light sent to the eye, irrespective of optical composition.

As illustrations of the constants, take two purples. One may be redder or bluer than the other; this is a variation in hue. One may be brighter than the other, this is a variation in luminosity. Lastly, one may be less decided, or paler, than the other, this is a variation in purity. Hue corresponds to a variation in the *quality* of the colour sensation. Tint depends upon the relative proportion of positive colour and of white light. Shade or tone depends upon the quantity of light of the given colour; and any colour will be lighter or darker in tone, according as it is more or less luminous.

69A. *Saturation, etc.*—If a colour is at once as rich (or pure) and as bright as possible, it is said to be completely saturated. The degree of saturation may be defined as the amount of positive colour per unit of surface. Take two red surface units, one with a luminosity of 100, of which 25 per cent. is white light, the other with a luminosity of 300, of which 50 per cent. is white light. Then the second surface is twice as saturated as the first, because it contains twice as much red on the same area, but the first is richer than the second because the proportion of red to white is greater. (These definitions are from Mr. Scott Taylor.)

A colour is said to be paler when it is at the same time brighter and mixed with more white light. A colour is said to be deeper when it is at the same time darker and purer, or mixed with less white light. White light being

brighter than light of any positive colour must always increase the total luminosity of any mixture of which it forms a part.

70. *Determination of the Constants.*—To determine the *first* constant, hue, a small strip of the spectrum is isolated, referred to the fixed lines, and named. A simple spectral colour may also be defined by its wave-length.

To determine the *second* constant, purity, is not easy. Suppose we have a paper, coloured by vermilion, we choose a spectral hue, which when mixed with white light, will match the vermilion. If we know the relative luminosities of the spectral colour and the white light, and can ascertain the proportion in which they are mixed, we obtain a value for this second constant. We can also by the method of rotating discs (Sect. 78) easily mingle white and any given colour in any required proportions.

It is an interesting experiment to throw a strip of white light upon a spectrum, and to notice the alterations produced in the colours. These appear paler and less pure. The following results of the spectroscopic examination of the light reflected from pigments will show how far such light is from being pure. The spectrum of a vermilion surface gave red, orange, yellow, green (darkened), blue (darkened), no violet. Emerald-green gave red (darkened), orange, yellow, green, blue, violet-blue (darkened), no violet. Artificial ultramarine-blue gave red, orange, yellow (all darkened), green slightly darkened, blue, violet. Chrome-yellow gave red, yellow, green, marine and blue (much darkened), no violet-blue, or violet. Supposing the total amount of coloured light from any one coloured paper to be divided into 100 equal parts, Prof. Rood estimates that vermilion reflects 80 of red and 20 of white, emerald-green about the same, artificial ultramarine-blue about 75 of blue and 25 of white. (Sect. 33.)

70A. *Luminosity.*—To determine the third constant (luminosity) is practicable in some cases; the problem is a

photometric one. Careful observations have been made on the luminosity of the different colours of the spectrum. Yellow is the brightest colour, then come green and red, whilst blue and violet are the least luminous portions.

If (taking a solar spectrum) we multiply the number, representing the luminosity of a given colour, by the number, representing the space such colour occupies in the spectrum, the product will represent the amount of light, of that colour, present in the white light, from which the spectrum was formed. The highest product is given by the greenish-yellow colour. The yellow, though the brightest portion, occupies so narrow a space that the product is lower than that obtained from some of the other colours; and, on the other hand, the violet space, though considerable, is so low in luminosity, that the product is very small. By the method of rotating discs (Sect. 78) we can easily blend black and a given colour in any required proportions, thus reducing the luminosity. (Sect. 195.)

For comparing luminosities, the best instrument is the spectro-photometer, which will now be briefly described. A direct vision spectroscope is provided with two slits, so as to form two parallel adjacent spectra. Each of the lights from the sources to be compared passes through a Nicol prism before falling on its own slit. The Nicols are so arranged that the light in the one spectrum is polarised oppositely to that in the other. Behind the spectroscope is placed a third Nicol, and by turning this the light of one spectrum is increased, and that of the other diminished. We isolate corresponding small parts of each spectrum, and turn the Nicol until these parts appear of equal intensity. The angle, through which the Nicol has been turned, affords the data for finding the relative intensities of any two corresponding parts of each spectrum. By summing the intensities for every part we should obtain the total intensities of each source of light. If the two sources of light are equal, we can easily estimate the absorptive effect

of any particular substance, by placing it in the path of one of the beams, and then comparing the spectra, portion by portion, as before.

But I confess I do not see how, even with this instrument, we could really compare, not a red with a red, but a red with a blue. The difficulty results from the fact that the eye does not measure the *total* energy of a coloured beam, but simply estimates, in a general sort of way, that part of it which is competent to excite *vision*. To be truly compared in intensity the two sets of waves must be of the same length, that is must belong to corresponding portions of the two spectra which they form.

70B. *Photometry.*—Photometry, or the measurement of the intensity of light, is in intimate relation with many matters connected with colour. Illumination depends partly on the eye and is some function of the total radiation. This function is partly subjective and varies with the colour of the light and with different eyes. So illumination cannot like radiation be expressed directly in absolute measurement. But the connection between the two can be determined by a large number of experiments, so as to get the value of the function for the normal eye. If it is found that the radiation spectrum, from some source of light, agrees with some one of the spectra, obtained from a standard source (say a carbon filament of known size consuming electrical energy at a definite rate), then photometry would be rendered accurate and simple, and we should simply have to adjust the current until the standard gave a spectrum, whose energy curve was similar to that of the light to be measured.

71. *Number of distinguishable colours.*—It has been estimated by one experimenter (I think he exaggerates) that the eye can detect, in a colour, changes of hue due to an addition of from 1.100th to 1.300th of the total: also that one part of white light can perceptibly change 360 parts of coloured light: and that differences in luminosity, as small as one part in 150 parts, can be recognised. The

above data would give 1,000 distinguishable hues in the solar spectrum; and these, by variations in purity and luminosity, and by the addition of the purples, would give a total of some hundreds of thousands. Every known colour can be imitated by selecting one (or in the case of the purples two) of the spectral hues, and suitably altering its (or their) purity and luminosity. It is easy by means of the rotating discs to experiment on the sensitiveness of the eye to small changes in the proportions of any mixture.

With a disc containing 4 parts of red, and 96 of white, I found the change from white was just perceptible, the mixed result being a very slightly darkened white, but I could not say the disc had any definite recognisable colour. Five parts of red and 95 of white produced the palest possible pink. A very little white was found to sensibly lighten a coloured disc. This one might have anticipated, because white is so much more luminous than most pigments. A disc, 2 parts blue and 98 red, gave a hue just perceptibly differing from the unadulterated red. It also appeared that a small quantity of blue was more effective in altering red, than was a small quantity of red in altering blue.

72. *Luminosity of Pigments.*—By means of Maxwell's rotating discs Prof. Rood has estimated the luminosity of several common pigments. A disc was painted with the pigment, and was then compared with a compound disc, in which, by adjusting black and white, a series of grays could be produced. It is difficult for me to understand how the eye can really estimate, except in a very rough and general way, that the luminosity of some pigment—say red—is about the same as that of one of the grays; but I give here Prof. Rood's results. Taking the luminosity of white paper as 100, vermilion is about 26, pale-chrome 80, pale emerald-green 49, cobalt-blue 35, artificial ultramarine 8, black-paper 5. It should be carefully borne in mind that neither the spectral red blue and green, nor the pigments most resembling those hues, have among themselves equal luminosities.

A gray, which would send to the eye an amount of light producing a stimulation equal to that produced by some given colour, might be called the *equivalent gray* of that colour. (Sect. 210.)

PART IV.—THE MIXTURE OF COLOURS.

"A."

73. *Superposition of Spectral Colours.*—Two spectra are formed, and so arranged that any two portions of them may be made to overlap. Two slits parallel to one another, the distance between them being capable of variation, or two slits crossing each other at an angle capable of variation, may be used. Either of these arrangements allows of two spectra being superposed so that different portions of them may be made to overlap. Another method is by means of a mirror to reflect any part of one spectrum on to any part of another. One spectrum may be used, and being received upon a series of mirrors, any portions of it may be reflected so that the images of the colours shall coincide upon a screen. If, in the path of the rays, which form a large spectrum upon a screen, a very small acute angled prism is held, it is very easy to deviate any portion of the coloured rays, so that it may be made to fall upon some other portion of the spectrum on the screen. The part of the spectrum on the screen, from which the rays are deviated, shows a dark patch, indicating accurately the position of the particular colour before deviation. The part of the spectrum, upon which this deflected colour falls, exhibits the hue due to the mixture of the hue of the part of the spectrum, upon which the deviated colour falls, with the deviated colour itself. This method is admirably adapted for lecture purposes, and I do not remember to have seen it described before. Certain portions of a spectrum may be stopped out, and the remainder combined by a cylindrical lens, or a second

(reversed) prism. Colour is thus produced by suppressing colour. Simply widening the slit, through which the light passes, will cause some of the spectral colours to combine. When the spectrum is one, which is produced by light previously passed through an absorbent solution, we can in this way cause the transmitted colours to blend.

Instead of viewing a slit of light through a prism, we can put a narrow strip of white paper upon a black ground. This will give a spectrum. A second strip will give another spectrum, and by adjusting the distance between the strips, and also by placing them parallel, or inclined to one another, any colours of the one spectrum can be made to fall upon any colours of the other. The results may be varied by placing black strips upon a white ground. A combination of a black triangle on a white ground with a white triangle on a black ground yields an enormous number of beautiful colour-mixtures.

74. *Maxwell's Colour Box.*—By Maxwell's Colour Box two or three spectral colours can be combined in any required proportions, and their mixture can be compared with and made to exactly match in colour and intensity a given standard white light. This most ingenious instrument depends upon the principle of optical reversibility. A pure spectrum is formed in the usual way, and then the positions of the eye and the slit are interchanged. The light is admitted through three slits, adjustible in width, and capable of being placed at any part of the screen, upon which the original spectrum (formed by light through what is now the eye-slit) fell. The exact position of the screen-slits is indicated by referring them to the fixed lines.

Lord Rayleigh has devised another form of Colour Box, which is compacter and also easier to use than Maxwell's. By it any two spectral colours can be combined in any proportion and compared with a third colour. Light is admitted through a slit, behind which is a double-image prism. A direct vision spectroscope forms two spectra of the double-

image of the slit. These spectra overlap, the amount of overlapping, and therefore the particular colours mixed at each point, will depend on the position of the double-image prism. In the two spectra the lights are oppositely polarised. Viewing them through a Nicol we can, by turning the Nicol, exactly adjust the proportion of the light from each which shall be present in the mixture produced by their overlap at any point. This mixture can then be compared with any given portion of a third spectrum, formed from an unpolarised beam. This instrument was used for obtaining the results referred to in Sect. 183.

It should be borne in mind, with reference to polarisation, that a Nicol transmits only half the light incident upon it, and that a double-image prism splits the light incident upon it, into two beams, each beam having about half the intensity of the original. In the foregoing methods, if the spectra are well formed, the colours are pure colours. The advantage of polarised light is that we are able with great facility to vary its intensity and to estimate accurately the amount of variation. The intensity of a mixture of coloured lights is the sum of the intensities of its constituent lights.

"B."

75. *Superposition of lights coloured in Transmission.*—Two lanterns are arranged so as to throw two discs of light on to the same part of a white screen; and coloured glasses, or liquids, are then placed in the path of each beam, so that each beam may be coloured by transmission through an absorbing medium. By slightly separating the discs the compound and the constituents can be viewed simultaneously. The colours are of course not pure colours. The intensity of the mixture is the sum of the intensities of the constituents. The intensity of the lights can be altered by regulating the lamps.

For private experiments there is no necessity to use lanterns. Two square panes of stained glass may be placed with two of their edges meeting at an angle, say of 60°. A

light put outside each pane will throw a coloured image of each pane upon a piece of paper, so placed as to form with the glasses the third side of a hollow triangular prism. The colours mingle on the paper, which can be viewed through the open ends of the prism. Gelatine films may be used instead of glass. A looking-glass makes a convenient adjustible second source of light.

"C."

76. *Blending by a Double-image Prism.*—A Double-image Prism is an instrument which produces two oppositely polarised images of any object viewed through it. Two beams of light coming through two coloured glasses, or from two patches of paper, are made into four, and it is easy to cause one of each pair to overlap and mix their colours. We see the constituents and the compound simultaneously. It is important to notice that though the intensity of the mixture is the sum of the intensities of the constituents forming it, yet each of these constituents has only half the intensity of the original; for the light from each source was divided into halves, and only one-half of each is used. (See end of Sect. 74.) As the lights, which form the mixture, are oppositely polarised, we can by looking at it through a Nicol prism (capable of rotation) easily and exactly adjust the proportion of the constituents, and this greatly adds to the value of the results. It is interesting to view a spectrum (either real or virtual) through a double-image prism, and so to cause various portions of its two images to overlap.

"D."

77. *Combined reflection and transmission.*—The two colours to be mixed are painted on paper and laid upon a black background. Between them is placed, upright, a sheet of clear glass. (Plate III.) It is easy so to place the eye that the reflected image of one colour overlaps the other colour seen through the glass. As the quantity of light reflected varies with the angle of incidence, there is no difficulty in varying the proportions in the mixture. This

method is adapted for mixing only two colours, and does not allow of exact estimation. The intensity of the mixture is the sum of the intensities of the reflected and transmitted constituents. This method can be modified, for mixing beams of coloured light, by using a bundle of glass plates, so arranged as to polarise (oppositely) the transmitted and reflected light. The mixture is produced as before, but the proportion of the constituents can now be accurately adjusted by looking through a Nicol prism, capable of rotation. This instrumental arrangement is called a dichroiscope.

In the method with the single glass plate, if (say) red and blue patches are placed on one side of the plate, and similar blue and red patches on the other, and we then adjust matters so that the two purple patches produced are alike, we shall know that we are using just half of each colour to produce the mixture, and the resultant hue will be a true mean.

"E."

78. *Mixing by rotation. Maxwell's Discs.*—Colours, painted sectorially on the same disc, are blended by retinal persistence, when the disc is rapidly rotated. Instead of painting colours upon the same disc, it is better to use a disc for each colour, and then by slitting each disc along a radius, two or more discs can easily be combined upon the same axis. By adjusting the angular magnitudes of the exposed sectors there is no difficulty in mixing colours in any proportion, and in expressing this proportion numerically by the number of degrees in each sector. (Plate III.) It is convenient to have discs of two sizes, large and small, so that simultaneous comparisons may be made between the small disc and the surrounding annulus of the large disc. Maxwell's ingenious colour-top is simply an arrangement for exhibiting the colour effects due to rotating discs.

The luminosity and hue of the mixture, obtained by rotation, are the mean of the luminosities and hues of the constituents.

79. *Modifications of the Method.*—I have found the following modification of the disc-method gives very beautiful and interesting results. A coloured sector, of any required angular magnitude, is rotated in front of a fixed coloured disc. By retinal persistence the colour of the sector is spread out into a sort of semi-transparent coloured circle, through which the fixed disc is seen, the colour of this disc being blended with that of the rotating sector.

Sometimes a disc with transparent coloured sectors is used, and is rapidly rotated in front of a beam of light, which passing through the disc exhibits upon a screen the results of the mixture of the sectors.

Instead of combining by rotation two simple sectors of two discs, we may superpose upon a disc a sort of compound sector, made up of a series of annular sectors decreasing in angular magnitude from centre to circumference. This arrangement, when rotated, gives us at one view a series of annuli, in which one of the colours is increased by successive steps. (Plate III.) Or, we may superpose upon a disc a heart-shaped piece of coloured paper, and so obtain a mixture of colours in which the proportions continuously vary from centre to circumference. (Sects. 208, 237.)

In the rotation method we are really blending together not the coloured lights themselves but the colour sensations they produce.

"F."

80. *Mixture by Adjacency.*—This is a method practised by artists in what is called stippling and cross-hatching. A number of fine dots or lines of the colours to be mixed are painted close together, and when seen from a distance, blend together in the eye. A fabric of which the warp and the woof are differently coloured would be a good example of mixture by adjacency.

"G."

81. *Mixture by the Stereoscope.*—The two colours are placed in a stereoscope, one under each glass.

"H."

82. *Mixture by exposing coloured objects to coloured lights.*—In this method we illuminate a coloured surface by one or more coloured lights. This is a case similar in many respects to (B), but complicated by the fact of the screen being coloured.

" I."

83. *Mixture of Pigments on the Palette.*—This is the method usually followed by the Painter. Neglecting the slight effect (due to mixture by adjacency) of the particles which constitute the surface mosaic—an effect which almost vanishes when the materials are well mixed with some oily medium—it may be said that, in mixing pigments, we do not really mix colours at all, but only the coloured materials. The colour seen is a residual after an absorption proportionate to the number of different pigments used. The intensity of the residual colour is lower than the mean brightness of the colours from which it results.

84. *Summary.*—In methods (A to G) we are truly mixing colours (or colour sensations) that is we add together coloured lights; in method (H) the coloured screen may introduce some absorptive effect; in method (I) we work not by addition, but subtraction, and are mixing pigments, not lights.

PART V.—RESULTS OF THE MIXTURE OF COLOURS.

85. *Production of White.*—If all the colours of the spectrum are re-united the result is of course the original white light. This re-union is easily accomplished by placing a second prism with its refracting edge parallel, but turned in the opposite direction, to that of the first prism: or by receiving a spectrum upon a series of small movable mirrors, which can be so adjusted as to throw the reflected images of the different colours on to the same spot; or by allowing a spectrum to fall upon a cylindrical lens. Also, we may simply widen the slit through which passes the light before it falls on the prism; this at once causes overlapping of the colours and the middle part of the now impure spectrum becomes white. (See also Sect. 101.)

By the colour resulting from the mixture of colours is meant the colour seen, when the given colours are caused to fall upon the same part of the retina, either simultaneously, or so near together, in time or space, that the impressions are perfectly blended.

86. *Propositions about Colour-mixture are subjective.*—Colours are sensations, and in mixing them we are blending sensations. Experiment must be the guide; but, after a good deal of experimental work has been done, we can by the help of it and of the Theory of Colour—to be presently explained—venture to predict results. The objective differences between optically simple colours are differences of wave-length (due to wave-frequency). To the spectroscope must be made the ultimate appeal, if we would know the simple constituents of any colour or mixture of colours.

87. *A Mean Hue.*—The hue of the colour due to the mixture of colours may be called the *Mean Hue* of those colours.

"A."

88. *Results of the mixture of pure Spectral Colours.* (*Sects.* 73-4.)—The spectral colours may be divided into three sets, green, and the colours on either side of green, red to yellowish-green, and violet to bluish-green. Taking the colours from red to yellowish-green, any pair give by mixture a compound colour, similar in hue to a simple spectral colour lying between the two. Red and yellow give orange, orange and yellowish-green give yellow, etc. A like result holds good for the colours ranging from bluish-green to violet. Bluish-green and violet give ultramarine blue, and so on.

89. *Peculiar action of Green.*—On the other hand, *green*, mixed with any other colour, gives a resultant less saturated, or whiter, than the most nearly corresponding simple colour. Green and red give whitish yellow, green and violet whitish blue. The green, which produces these effects most markedly, is a slightly bluish green, and is called by Müller the Fundamental Green; it lies near the fixed line b on the more refrangible side of E. (Sect. 147.)

90. Taking now a pair, one colour more, the other less, refrangible than green, it is found that red and ultramarine give whitish violet, orange and violet whitish red, orange and ultramarine whitish purple, red and violet (or red and blue) purple.

These results will be explained by the Theory of Colour. (Sect. 147.)

91. *Complementary Pairs.*—Finally, pairs of colours may be so chosen that the result of their mixture is not coloured, but white, light. Such colours are called complementary. (Sect. 128.) Chosen from the spectrum one of such colours must be more, the other less, refrangible than green. The

following are complementary pairs, red and marine, orange and greenish-blue, yellow and blue, greenish-yellow and violet.

To green no single spectral colour is complementary; and, in order to produce white, green requires purple (a mixture of red and blue); *i.e.*, the middle colour requires a mixture of the two extreme colours. The whites produced in this way are to the eye quite indistinguishable from ordinary white light, which—as we know—contains every spectral colour; but a prism at once reveals the difference.

If the spectrum be divided into any two parts, and the colours of each part be separately combined, then the mixture of these two compound hues will of course produce white, as it will contain all the spectral colours. Any single selected colour is really complementary to the sum of the colours remaining.

92. *Union of Three Colours.*—To unite more than two spectral colours, Maxwell's colour-box (Sect. 74) is the best arrangement. With it there is no difficulty in showing that red green and blue (or violet), in certain proportions, give a perfect white, identical with the white produced by combining the whole of the spectral colours; but of course the intensity of the white, produced by combining all the spectral colours, will be greater than that of the white produced by combining only the red green and blue portions of the *same* spectrum.

With his colour-box, and using three colours, Maxwell found that the colours from red to yellow must be combined with green and blue, the colours from yellow-green to marine with red and blue, and those from greenish-blue to violet-blue with red and green, in order in each case to produce white; the red green and blue being certain chosen hues defined in position by the Fraunhofer lines.

It appears, as a result of experiment, that every known colour can be imitated by a spectral colour (or in the case of the purples by two spectral colours), provided we can, if necessary, alter the intensity of the spectral colour, and can also, if necessary, dilute it with white light.

93. *Luminosity of a Mixture.*—It will be remembered that the luminosity of the mixture of two superposed coloured lights is the sum of the luminosities of the two, and is therefore brighter than the brightness of either constituent, so that when yellow, purple, or marine, is formed by blending red and green, red and blue, or blue and green, lights, the luminosity of the mixture will be greater than that of either of the constituent lights out of which it is formed. In Sects. 70A and 72, the luminosities of the spectral colours and of some pigments were given. We know that red blue and green lights make white when mixed. According to Rood spectral green is the brightest of these three, then come red and blue. It follows that the joint luminosity of red and green (which form yellow), or of blue and green (which form marine), considerably exceeds the luminosity of the blue or red respectively. The luminosity of purple (red and blue) and of green will be more nearly on a par.

"B."

94. *Results of the mixture of lights coloured in transmission.*—When lights, which have been coloured by transmission through absorptive media, are mixed, the results are very similar to those obtained by blending spectral colours, but are modified by the fact that the transmitted colours are not pure.

With blue and yellow glasses the discs of light blended on the screen (Sect. 75) will be white, if the glasses are carefully chosen and the two lights are of proper intensity. Usually however the compound disc is of a pinkish tinge, due to the fact that many blue glasses transmit some, and all yellow glasses a great deal of, red. With red and blue glasses a good purple is produced. Red and green give a yellow, which is made orange by diminishing the green, and greenish-yellow by diminishing the red. Violet and green give blue; blue and green marine; yellow and red orange; yellow and green yellowish-green. Coloured liquids produce similar results.

95. *Contrast with the effects of superposition.*—If instead of mingling the lights from the two lanterns, we use one lantern and place both glasses in front of it, we get the effect due to double absorption, not to mixture. Through yellow and blue glass, green (dull) is transmitted; through red and blue, only red; through deep green and red, no light. Through yellow and green is transmitted a dull yellowish-green; for all yellow, and most green, glasses transmit both yellow and green; through blue and green is transmitted a dull marine; for most blue and green glasses transmit respectively some green and some blue, besides their own colour. In no case are the mixture results *identical* with the absorption ones, and in the majority of cases they differ widely. If the glasses were pounded and mixed together with oil, the colour of the mixture will be the same as the colour of the light transmitted through the two combined glasses before they are crushed.

The light through blue solution of copper sulphate, and that through yellow solution of picric acid, produce white by mixture. Similarly, the mingling of the lights, transmitted through blue ammoniacal copper sulphate and orange potassium bichromate, produces white. The former pair, if superposed, allow a bright green to be transmitted, the latter allow only a small amount of very dark green, and, if taken in sufficient thickness, the combination is opaque.

96. The following example well illustrates the need of careful spectroscopic examination of the media used. The light passed through a rosy film of gelatine, and that passed through a blue film, were found to give a beautiful pale puce purple, when mingled upon a sheet of white paper. Placed one behind the other, the films also furnished a purple; but in this case the colour was a dark purple. Here it seems as if the red and blue films mingled their colours in transmission. Spectroscopic examination at once solved the difficulty of the transmitted purple. The rosy film transmitted red orange blue and violet, the blue film transmitted

red green blue and violet; through both then there passed red blue and violet, thus accounting for the purple. But in the case of superposition the green and orange were absent, and so we see a pure dark purple.

"C."

97. *Results with the double-image prism.*—The double-image prism method (Sect. 76) gives results agreeing with those already described. By the prism experiments can be rapidly and readily made upon the infinite variety of hues furnished by pigments, etc. But it must be remembered that two images of each colour are formed, and that each of these has only half the intensity of its original. It is easy so to adjust the patches looked at and the prism, that we see at the same time one of the images of one colour falling partly on its fellow-image and partly on one of the images of the other colour; similar arrangements holding for the other colour. We then see five results: (1) an image of the first colour, half as bright as the original: (2) two superposed images of the first colour, exactly resembling the first original colour viewed without the prism: (3) two images, one for each colour (each half the intensity of its original), blended by the superposition into a new colour, whose intensity will be the mean between the intensities of the original colours: (4) two superposed images of the second colour, exactly resembling the second original colour viewed without the prism: (5) an image of the second colour, half as bright as the original.

Seen through a Nicol prism, the compound images (2) and (4) lose half their intensity, but do not alter for rotation of the Nicol; the simple images (1) and (5) retain their full intensity for particular positions of the Nicol, and vary from that to zero as the prism is rotated; the compound image (3) loses half its intensity, and, when the Nicol is rotated, varies in colour, becoming identical with (2) or (4) at the extreme positions of the prism, and showing the mixture-colour due to varying proportions of the two colours, as the

Nicol rotates between its extreme positions. The intensity of this compound image (3) will vary as it varies in colour, unless the two original colours are of equal intensity, and this is seldom the case.

A very good gray may be made by combining blue paper and yellow paper by the double-image prism, and then, if necessary, adjusting the proportions by the Nicol. With green and violet papers the blue produced is rather "slaty" in character. Red and green give dull buff yellows. Red and blue produce good purples.

For the use of the double-image prism in blending spectral. colours, see Sect. 74. It certainly seems to me that theoretically the blending of spectral colours by this prism is the really correct way, if we wish the mixture to have an intensity comparable with the intensities of its constituents. For, in ordinary superposition of spectral colours, we get a mixture, whose intensity is the *sum* of the intensities of its constituents; but, in using the double-image prism, each constituent is halved first, and only the halves are blended, so that the intensity of the mixture is a true *mean* between the intensities of the original constituents; and this condition of things will prevent the complication that arises from the fact that change of intensity influences the hue of a colour. (Sects. 190, 244.)

"D."

98. *Results by combined transmission and reflection.*—The results obtained by combined reflection and transmission (Sect. 77) resemble those already described. With the glass plate it is easy to show that the image of a blue paper, thrown upon a yellow paper, produces a grayish white. Similarly red and green papers give a dull yellow; red and blue a purple; emerald green and aniline violet a series of pale blues; a dark green with the same violet a fairly good blue, and so on. (Plate III.)

With a dichroiscope, and using coloured glasses to colour the two oppositely polarised beams, I find that blue and

yellow give a faint pink, that is a white reddened by the excess of red escaping neutralisation. Red and green give a dull yellow; blue and red a purple; etc. On looking through a Nicol and rotating it, the proportions of the two beams can be easily adjusted.

99. *Details.*—I give here for comparison the results of mingling by the double-image prism the lights from two coloured glasses, and the results of passing the light through the same two glasses superposed. Yellow and blue give (by the prism) rose-pink, but, when superposed, olive green. Another pair give respectively gray and full green. Red and blue give purple and deep red; blue and green give bluish-green and marine; yellow and red give orange and a scarcely altered red; red and green (various pairs) give greenish-yellow and brown, pale-yellow and brownish-green, orange and darkish red, brown-yellow and very dark brown. Green and purple give greenish-gray and neutral tint; and another pair give light marine and dark marine. Purple and blue give bluish-green and dark violet. The most curious result occurred with a certain yellow glass and purple glass. Combined by the double-image prism they give a yellow just a shade deeper than the yellow glass. Superposed the colour is orange. With the spectroscope it was found that the yellow glass transmitted red yellow green and some blue, and that the purple glass transmitted red violet-blue violet and a little green.

"E."

100. *Results with Rotating coloured Discs.*—The rotating-disc method of mixture (Sects. 78-9) is one of the simplest, and has led to most valuable results. It allows of any number of colours (impure ones of course) being combined in any desired proportions, and matches can easily be made between one set of discs and another smaller set mounted on the same axis. (Plate III.)

A blue and a yellow disc, so adjusted that half of each is used, gave by rotation a light gray. The mixture is not white, because neither the yellow nor the blue is so bright as white, and the luminosity of their mixture by rotation is the mean of the luminosities of the two colours. Red and green discs give a yellow or pale buff. A fairly good yellow can be made by taking a yellowish-red and a yellowish-green. Red and blue give a purple; violet and green a fairly good but rather grayish blue; green and blue a marine; red and yellow an orange; green and yellow a yellowish-green; marine and vermilion, a gray.

Dividing the disc into 100 equal angular parts, a mixture by rotation of 42 of artificial ultramarine with 58 of pale chrome-yellow gave a gray, which was almost white, but had a slight tinge of heliotrope. This tinge would be due to a small trace of purple escaping neutralisation, the purple resulting from the red (present in all yellows) and the blue. When cobalt blue (which is greener than ultramarine blue) was substituted, the tinge of purple disappeared. With 50 of ultramarine and 50 of deep chrome, a pale purple gray was produced, the purple tinge again almost vanishing when cobalt was substituted for the ultramarine. Emerald green 50 and vermilion 50 give a dull yellow; emerald green 25 and vermilion 75, a dull orange; emerald green 67 and vermilion 33, a pale yellow-green. The half and half emerald and vermilion matches a disc containing 50 black, 15 white, and 35 pale chrome-yellow. A disc with 50 red-lead and 50 green-bice gives a palish chrome-yellow colour. Aniline violet 25 and Hooker's green 75 give a marine; violet 50 and Hooker's green 50, a medium blue; violet 75 and Hooker's green 25, a dark blue. Violet 50 and emerald-green 50 give a marine; violet 75 and emerald green 25, a pale slaty blue; violet 25 and emerald green 75, a slightly bluish-green. Red and black give a series of browns. Red purple (Hofmann's violet RRR) and cadmium orange, in equal parts, gave on rotation a beautiful pink colour. The blue of the purple, and the yellow of the orange,

disc, will form a white, and then the excess of red in each will colour this white, and so form pink, which will also contain some blue, if all of the blue is not neutralised by the yellow.

100A. The mixed colour may be regarded as a mean of the colours of the several sectors. We find that 64 parts of marine with 36 of vermilion produce a gray, matched by 21 of white with 79 of black. The gray is therefore about four times less luminous than white itself. So again 50 of gamboge and 50 of cobalt-blue give a gray (perhaps slightly greenish yellow); whilst 50 of gamboge and 50 of ultramarine give a gray, slightly pink; the difference between the grays being well seen, when they are simultaneously produced. These grays, so far as they are gray, can be matched by mixtures of black and white. (Sect. 137.)

From no rotation mixture of yellow and blue could a real green be got, though, if we use a greenish yellow and a greenish blue, the gray will be somewhat tinged by the excess of green present in both colouring the gray produced by the yellow and the blue.

It was mentioned that ultramarine and pale chrome-yellow gave a slightly pink or purple gray, due to some little red and blue escaping neutralisation. If a small quantity of emerald-green is introduced, the gray becomes normal. I found with certain pigments, that $44\frac{1}{2}$ pale chrome with $9\frac{1}{2}$ emerald-green and 46 ultramarine, just matched a disc half white and half black.

100B. *Modified Sectors, etc.*—An immense series of colour-mixtures can be obtained by varying the angular magnitude of the sectors of each disc. If a coloured sector, compounded of a series of portions of concentric annuli of successively decreasing angular magnitudes, be superposed upon a coloured disc, we get, on rotation, a series of coloured annuli exhibiting compound colours, containing a successively decreasing quantity of the colour of the sector and a successively increasing quantity of the colour of the disc, as

the annuli are seen further and further from the centre. By superposing on the disc coloured pieces of different shapes, interesting and beautiful results are obtainable. For instance, with a heart-shaped piece of blue card superposed upon a disc of yellow card, we see, on rotation, a blue central circle, surrounded by a coloured surface, which passes insensibly into gray, and then into yellow. (Sects. 79, 208, 237, and Plate III.)

101. *Newton's Disc, etc.*—Again, using three coloured discs, a match can be made between the rotation mixture of 50 green, 24 blue, and 26 red, and the gray made from 28 white and 72 black. These numerical coefficients hold good only in daylight, and for the particular pigments used. The gray thus made is about $3\frac{1}{2}$ times darker than white.

A disc, painted with sectors representing in hue and proper proportion the spectral colours, will appear grayish white when rotated. Such a disc is often called Newton's Disc.

102. *Luminosity of rotation mixtures.*—Consider briefly the luminosity of rotation mixtures. Prof. Rood estimates the luminosities of emerald-green, vermilion, and ultramarine, at $48\frac{1}{2}$, $25\frac{1}{2}$, and $7\frac{1}{2}$, respectively (white = 100). Then suppose we take equal semi-circular areas, and combine the pigments in pairs. The luminosity of the rotation mixture of emerald-green and vermilion will be the mean, or half the sum of the luminosities of the colours, that is 37; so also the mixture of the green and blue will give 28, and of the red and blue, $16\frac{1}{2}$. The luminosities would have been just twice as great had we been able to add them, as we can add those of coloured lights. These examples will show how difficult it is to truly imitate with pigments the results obtained with coloured lights.

103. *Detached Sector.*—When a rotating sector simply is used, and a coloured surface is viewed through it (Sect. 79), there appear to be *slight* differences between the mixture thus produced, and the mixture produced by making the sector part of a rotating disc, the other part of which is coloured the same as the coloured surface just

named. It is easy to place both arrangements of sectors on the same axis. This subject would be worth investigating, but is not a very easy one.

104. *Colour Equations.*—The results recently given may be written in an equational form:

$$24 \text{ blue} + 50 \text{ green} + 26 \text{ red} = 28 \text{ white} + 72 \text{ black.}$$

Here = means matches in colour, and the numbers represent the angular magnitudes of the different sectors; whilst + denotes superposed on (the superposition being due in the case of discs to retinal persistence). The resultant tint in the above equation is a gray. Maxwell's colour-box also furnishes colour-equations; thus the equation:

$$18\tfrac{1}{2}\ (24) + 27\ (44) + 37\ (68) = W$$

means that the breadth of the slit was represented by $18\frac{1}{2}$, whilst its centre was at division 24 of the graduated scale to which the spectral colours were referred; and so of the other two colours; the sum of the three producing a result which exactly matches a constant white (W).

Again, divide the disc into 100 equal parts. Fill it with 28 red, 28 green, and 44 blue. The intensity of the red will be 28-100th of the actual red, and so of the other colours. Thus the resultant colour, which we may call C, will be denoted: (28 red + 28 green + 44 blue) divided by 100, or,

$$28\ R + 28\ G + 44\ B = 100\ C.$$

105. Colour-equations can also be obtained when coloured lights, which have been oppositely polarised, are mixed and viewed through a Nicol prism; for the angle of rotation of the prism enables us exactly to determine the relative intensities of the constituents.

These equations can be combined and dealt with after the manner of ordinary algebraical equations.

The introduction of measurement, of *quantitative* relation, into colour experiments, is a step of the utmost importance, and gives a scientific value which is quite wanting in experiments that are merely *qualitative*.

The following illustrates the way in which two equations can be made use of to obtain a third equation. (Sect. 121.)

$18\frac{1}{2}$ red + 27 green + 37 blue = white.
16 orange + 21 green + 37 blue = white.

By subtraction :—

16 orange = $18\frac{1}{2}$ red + 6 green.

"F."

106. *Results of mixture by Adjacency.*—The results of the adjacency method of mixture (Sect. 80) agree with those already described. Fine lines of cobalt-blue and chrome-yellow, placed in parallel alternation near together, yield a grayish white, containing no trace of green. Emerald-green and vermilion-red furnish a dull yellow; ultramarine-blue and vermilion-red a rich red-purple. This method is almost the only one by which the artist can actually mix, not pigments, but coloured lights. (Ruskin refers favourably to this method in his book on Drawing.) To this stippling, or fine mosaic work, is due the luminous and sumptuous effect of many paintings. (Sect. 299.)

Nature herself gives us many examples of adjacency mixture. The colours of the hill-side herbage mingle with the gray-green of the mosses, and the brown of the dried fallen leaves. So also the patches of lichen blend their tints with those of the trees or rocks upon which they grow. (Sect. 308.)

(For lustre in connection with adjacency, see Sect. 109.)

"G."

107. *Results of Stereoscopic mixture. Lustre.*—The results of stereoscopic mixture (Sect. 81) are very curious. Let the two colours placed in the stereoscope be blue and yellow. Some observers say they see the colours blended into a grayish white. Other observers (including myself) perceive a fluctuation. Both colours are seen, each as it were shining through the other, and struggling for the mas-

tery, so that there is the appearance of a body possessed of two colours. I have never succeeded in really blending the colours.

But the most remarkable feature is the *lustrous* aspect. This peculiar effect is well seen when the attempt is made to binocularly unite black and white. Stereoscopic drawings of a crystal, one white on a black ground, the other black on a white ground, present under the stereoscope the appearance of a semi-transparent crystal of shining graphite. The explanation is not easy; it probably involves an illusion of the judgment. If a polished object is so placed that its bright surface reflection reaches *one* eye only, there is a produced a very peculiar and confusing sensation. (Gold letters printed on a card answer very well.) It may be, then, that when the attempt is made to present simultaneously by the stereoscope two different colours, the differential effects on the eyes irresistibly suggest a polished surface placed as described, and making a fluctuating appeal to each eye in turn. The stereoscopic mixture differs then from the rotating-disc method in that the components do not disappear in the mixture; we seem to see both at once.

108. Lustrous phenomena, due to binocular vision, occur frequently in nature in connection with shining surfaces of water, etc., and are, of course, quite incapable of reproduction by the painter, who must necessarily present the same hue to both eyes. But, by varnishing a picture, or covering it with glass, a general lustrous effect is produced, when the reflected light from the varnish or glass reaches one eye only. Stereoscopic photographs can be made by combination to represent the sheen of water or leaves. (See also Sect. 38.)

109. *Dove and Helmholtz on Lustre.*—According to Dove's theory lustre is produced when two images act simultaneously upon the eye, and we are aware that there are two. Even with a single eye lustre is producible by the

more or less imperfect blending by adjacency of small coloured images. One image is, as it were, seen through the other. The maximum effect is produced by bright complementary colours. (Sect. 299.)

As the union of white and black in the stereoscope does not produce gray, but an effect of lustre, Helmholtz is of opinion that the impressions on the two retinæ are not combined into one sensation. He also thinks that the effect of lustre is not due to retinal rivalry, that is to alternate action of the eyes, for he says the lustrous appearance is still visible, when the illumination is the momentary one given by an electric spark.

The question of what really occurs in stereoscopic mixture of colours is however still apparently open to discussion, some holding that the combination colour is really seen, others that what is seen is merely an effect due to contrast.

"H."

110. *Coloured objects seen by coloured light. 1st, Monochromatic.*—When the object, illuminated by a coloured light, or lights, is itself coloured (Sect. 82), the results are somewhat complicated, for we get an effect due partly to true mixture and partly to absorption. If the light be *monochromatic*, such as is furnished by an isolated spectral beam, or by burning sodium, it might be expected that only objects, which reflected the monochromatic rays, would be visible. But the surface-reflection comes into play more or less in the case of practically all substances, so that, even from a substance, which would yield no yellow light by internal reflection, there is a surface-reflection of it; and the colour seen, in the case of blue violet and black substances, illuminated by sodium light, is a yellow of very low luminosity, a yellow much darkened, and appearing tinged with olive-green.

Still the general effect of viewing a chromolithograph by sodium light is that it appears like a work in monochrome, a sepia or india-ink drawing; for the yellow portions—though really yellow—are considered white, owing to the illusion,

explained in Sect. 117. A bouquet of coloured flowers is strangely altered in a similar way. The human face becomes cadaverous, and rosy lips appear quite livid. This experiment with sodium light teaches very plainly that, though a rose is red, yet the redness is not in the rose. (Sects. 1 and 8.)

110A. *2nd, Complex light.*—If the illuminating beam be of a colour which is complex (such as are almost all the beams transmitted through coloured glasses), the results may be shortly stated as follows.

Let the beam be a blue one produced by a blue glass which also transmits green. A blue screen, lighted by such a beam, will look blue, a green one green, by internal reflection, but the hue in either case will be modified by the surface reflection of a blue light, the same in both cases. A beam of ordinary yellow light contains red green and yellow. Illuminated by this light a Prussian-blue surface looks green, an ultramarine-blue one slaty gray. With the Prussian-blue there is absorption of the yellow and red, and internal reflection of the green; and though there is a surface-reflection of the original yellow light, this is not powerful enough to much alter the results. On the other hand, with the ultramarine, there is no internal reflection, for the pigment absorbs green as well as red and yellow, so that, strictly speaking, it would, except for surface reflection of the yellow, look black. But, if the ultramarine be illuminated by feeble daylight, as well as by the strong yellow light, it appears white, owing to the blending of the blue (internally reflected after selective absorption of the daylight) with the original yellow due to surface-reflection of the dominant illuminant. Purple, being a mixture of blue and red, appears blue in the blue rays and red in the red rays.

111. *A Dominant Light.*—Very numerous experiments have been made to determine the colours produced when a coloured surface is, at the same time, illuminated by two

coloured lights, one of which may or may not be sufficiently bright to be called a dominant light. It will be seen that the resultant tint depends upon four circumstances: the two unchanged surface-reflections, and the two internal-reflections after absorption. If one of the lights be white, we have only three things to consider: the "local" colour due to the change of the white light by absorption; the colour due to surface-reflection of the coloured light; the colour due to the change of this coloured light by absorption. (The surface-reflection of the white light may be neglected.) From a large series of experiments Prof. Rood draws the conclusion that the main effect is due to the combination of the local colour with the surface-reflected coloured light, and that the change of the coloured light by absorption acts only a minor part.

112. *Details.*—A few examples (taken from Prof. Church's book) of the appearance of coloured surfaces under the light transmitted through coloured glasses may be given. Such results hold good only for particular pigments and particular glasses.

Red light falling on yellow, green, and violet, surfaces makes them appear orange, yellow-gray, and purple. *Yellow* falling on red, green, blue, violet, makes them appear orange-brown, yellow-green, slate-gray, purple-gray. *Green* falling on red, blue, violet, produces yellow-brown, bluish-green, bluish-gray. *Blue* falling on red, orange, yellow, produces purple, plum-brown, yellow-gray. *Violet* on red, orange, yellow, green, blue, produces purple, reddish-gray, purplish-gray, bluish-gray, bluish-violet.

Upon a white surface all these lights are unchanged; upon a black one, red, yellow, green, blue, and violet, produce rusty-black, olive-black, dark green gray, bluish-black, and violet-black.

113. I give here the results of some of my own experiments, day-light, coloured by transmission through coloured glasses, being used. The words given in brackets denote the

new colour. *Yellow* light falling on marine produced (yellow-green), ultramarine (white), Hofmann's BB violet (scarlet), purple (orange-red). *Red* light on aniline green (grayish red-orange), marine (puce-red), Prussian blue (reddish-purple), ultramarine (red-purple), violet (red), purple (deep red). *Green* light on carmine (yellow), marine (green), Prussian blue (dull-marine), ultramarine (greenish-blue), violet (bluish-marine), purple (dull green-gray). *Blue* light on carmine (purple), vermilion (gray-purple), orange (white-purple), chrome yellow (white), emerald green (blue), marine (bluish-green), bluish-green (rich blue), violet (deep blue), purple (violet-blue).

114. It is an interesting and a simple experiment to cause coloured papers to reflect light upon one another. Place two papers with their colour surfaces parallel and near together, and let the light falling upon one of them be reflected to the eye from the other. Under these circumstances a gamboge surface looks whitish, when seen by the light reflected on it from a cobalt surface; vermilion looks orange by the light reflected from emerald green; and so on.

115. *Illustrations from Nature.*—Some of the grandest natural chromatic effects are due to simultaneous illumination by differently coloured lights, as when objects receive at the same time rays from a blue sky, and from an orange sunset. Minor cases constantly happen, as when a coloured object reflects light of its own tint upon neighbouring objects, modifying their hues, and being in turn modified by the light reflected from them. When the object is white or gray, the results are those due to the mixture of coloured lights; but, when it has a strong colour of its own, the results are modified by absorption. The slight and subtle varieties produced are infinite, and greatly tax the power of the artist, who soon learns that a uniformly coloured object is scarcely to be found in nature.

A ripe cornfield under an autumn sunset is a beautiful example of the rich effect due to a dominant light falling on a substance capable of largely reflecting it. So also a red brick house at sunset glows almost as if it were red hot. The colour of the ordinary blue sky is a blue mixed largely with white, so that objects lighted by it are not changed in the way they are when lighted by the red light of sunrise or sunset; still there is a perceptible difference between the colours of objects lighted by a blue sky and lighted by white clouds, the light from the sky being relatively poorer in the less refrangible rays. (Sects. 118, 320.)

115A. *Coloured Stars.*—Although the majority of stars are white, some possess decided colours, being red yellow blue or green. In many double stars the components are strongly contrasted in hue. If these double stars are the suns of planetary systems, the colour effects must be very gorgeous. If the planets are attended by moons, the chromatic display, as these wax and wane, and the weird effects seen on the occurrence of solar and lunar eclipses, must be beyond conception magnificent. Sometimes one sun may be above the horizon. Sometimes the planet will be coloured with a glow due to the blended illumination of both its luminaries. One moon may show a red crescent, another a blue, another may have one half red the other blue, a fourth may present a rich purple, due to mixed illumination, and so on.

116. *Ordinary Artificial Illuminants.*—We now pass on to consider the appearance of coloured objects under the ordinary artificial illumination produced by gas lamps or candles. This sort of illumination is relatively deficient in violet and blue, and relatively abundant in yellow. Pale yellows appear white, owing to an illusion of the judgment. Blues, violets, purples, and some greens, are greatly changed. Blue pigments, which contain green, have their green element strengthened by the enfeeblement of the blue, and it becomes difficult to distinguish some blues and greens. But a blue, like ultramarine, which is nearly free from green,

but contains violet, looks much duller, and is easily distinguished from a green. Purples look redder from the partial suppression of the blue. Ordinary violet pigments (which always contain some red), undergo a similar change. Greens are made yellower, but some aniline greens are scarcely altered. Reds become orange tinted ; marines are made greener ; pale blue looks gray ; carmine (a purple-red) becomes bright red. The lime-light and the electric-light contain plenty of blue and violet rays, and produce illumination like that of daylight. By the side of the electric-light a gas-light looks yellow or even orange.

117. *Illusions due to Coloured Illumination.*—The judgment often seriously interferes with our perception of a colour, when it is viewed under conditions of illumination different from the ordinary normal daylight. We are liable unconsciously to make an allowance for the change of conditions, and to still call the colour by what we may term its ordinary daylight hue. By gas-light all white surfaces are really yellow, but we call them white, and so have a false standard for other colours. So also, if we take a red paper into a darkened room, and so make it brown, we still call it red, for we unconsciously allow for the darkening.

We know that compared with daylight gaslight is yellow, but we do not realise how much the two lights differ until we place them side by side. The shadow of a rod, cast by either daylight or gaslight alone, looks gray, but if the two lights are used to cast simultaneously two shadows of the same rod, one shadow will appear yellow and the other blue. (Sect. 224.)

Pictures painted for daylight are often seriously altered when seen by gaslight. The best remedy is to use the lime-light, or the electric-light, both of which resemble daylight.

What is constant in the colour of an object is, not the brightness and colour of the light which it reflects, but the relation between the intensity of the different coloured ele-

ments of this light on the one hand, and that of the corresponding elements of the light which illuminates it on the other. This proportion expresses the constant property.

118. *Matches by daylight and by gaslight, etc.*—When a match has been obtained in daylight, it by no means follows that the same mixed colours will match by gas or candle light. In one experiment with discs, 23 blue, 44 green, and 33 red, matched a gray made of 28 white, and 72 black; the light being daylight. By gaslight the match no longer held (the triple mixture being purplish), and the colours had to be taken thus: 24 blue, 50 green, and 26 red. The green is increased, the red diminished, the blue very slightly increased.

These alterations are required by the fact that gas-light is relatively deficient in blue and violet. It might have been expected that the portion of the blue disc would have needed a larger increase, but almost all greens reflect some blue, so the blue element was strengthened when the green was increased. A colour match is easily destroyed by viewing it through a coloured glass which acts unequally on the different elements. The match given above is quite destroyed if the discs are viewed through a yellow glass.

Careful experiments in matching coloured discs will also reveal the difference between the light from a white cloud and that from a blue sky. Lord Rayleigh found that, in the matches obtained in the latter case, more red had to be introduced. (Sect. 115.)

"I."

119. *Results of Palette Mixture of Pigments. (Sect. 83.)*—It has been already fully explained that the mixture of pigments is a process totally different from the mixture of colours (i.e. coloured lights), and gives rise to different results. The essential diversity is best shown by contrasting the results obtained, by mixing two pigments on the palette, with those obtained, by mingling by rotation the coloured

lights from the same two pigments. Any two pigments being taken, washes are prepared from each : of these washes equal quantities are mixed, and with the mixture a small disc is painted. Two large discs are separately painted, one with each colour wash, and these discs are fitted, so that half of each goes to form the compound disc, whose colours are to be mingled by rotation.

120. *Contrast between palette and rotation mixture.*—Yellow and blue give gray by rotation, but green on the palette ; red and green give dulled yellow by rotation, but a brown-purple on the palette ; red and blue give rich red-purple by rotation, but a dull gray violet-purple on the palette. Can the palette-colour of the small disc be matched by readjusting the proportion of the two large discs, which it will be remembered are separately coloured with the pigments before mixture? This does not appear possible. In every case a *black* disc has to be introduced, showing the loss of light (due to absorption) in the palette mixture. But in very few cases indeed is it sufficient to introduce black. In the vast majority of instances some other disc, or discs, must also be introduced ; either a white disc, or a coloured disc, or both. A disc, painted green by a mixture of Prussian-blue and gamboge, was matched by a combination of four discs, whose exposed sectors were as follows : 8 gamboge, 20 black, 30 emerald green, and 42 Prussian-blue. A disc, painted dull purple, by a mixture of ultramarine and vermilion, was matched by rotating 55 black, 14 white, 8 vermilion, and 23 ultramarine. A disc, painted brown-purple by a mixture of carmine and deep Hooker's-green, was matched by rotating 45 carmine, 20 Hooker's-green, 17 Prussian-blue, and 18 black. The large amount of black, that it is necessary to add, strikingly illustrates the general proposition—that every mixture of pigments on the palette is a *stride towards blackness.* I may mention (as another example) that the rotation mixture of 50 gamboge with 50 Prussian-blue was a pinkish gray ; whilst the green

palette mixture of the same pigments was nearly matched by a disc with 12 gamboge, 40 emerald-green, 36 Prussian-blue, and 12 black.

An experienced painter, with perhaps a dozen pigments on his palette, is able, by what seems an unerring instinct, to so mix them as to imitate with wonderful accuracy the multitudinous hues of natural objects. This instinct is really the outcome of prolonged labour, aided by a gifted sense for colour.

Sir John Collier gives the following list of pigments as sufficient for all ordinary purposes: brown ochre, yellow ochre, Naples yellow, pale cadmium yellow, white, orange-vermilion, light red, Chinese vermilion, rose-madder, burnt sienna, emerald oxide of chromium, cobalt, ivory black, and Vandyke brown.

The more opaque the pigments mixed together, the more will the effect of their mixture resemble that produced by mixing lights corresponding to them; for the effect with opaque bodies must depend upon the adjacency mixture of the particles on the surface. If we mix on the palette a nearly opaque blue and yellow, the green is very dull, and is made worse by the white produced from the surface mixture. If each pigment transmitted only one pure spectral colour, then a mixture of two such pigments would be black, so far as the colour depends on internal selective absorption, and we should get only the mixed surface colour due to adjacency.

121. *To the eye, Sums of similar lights are similar.*—Colours, however produced, which appear identical to the eye, yield when their lights are mixed a mean colour identical with themselves. To this physical fact it is due that colour-equations yield true results when treated after the manner of ordinary equations. (Sects. 104-5.)

122. *Colours identical to the eye, may be optically very different.*—This important proposition has been already mentioned. The simple yellow of the spectrum may be

exactly imitated by a mixture of spectral red and green. The white, produced by recombining all the spectral colours, is undistinguishable from the whites produced by combining the spectral yellow and blue, the spectral red and marine, etc. The difference between these whites would be at once revealed by the prism, by looking through a coloured glass, or by receiving the light on a coloured screen (selective absorption.) Also, if a photograph be taken of a surface illuminated by a white light composed of blended red and marine light, the picture comes out black. But, with a white light made of yellowish-green and violet, it comes out white. (Sect. 13.)

123. *Yellow and Blue make a white; Red and Green a yellow.*—The two most interesting and important results in colour-mixture are (a) yellow and blue give a white (or gray), not a green; (b) red and green give a yellow. Taking the four colours red, yellow, green, and blue, most people, I think, see a resemblance between orange and the yellow and red of which it may be made, and a similar resemblance between marine and green and blue, and between purple and blue and red. But in yellow we are not reminded of red and green, and white certainly does not suggest blue and yellow.

Again a darkened red or orange suggests its original so little that it receives a new name—brown, but a dark blue is still a blue.

Many people believing the old error (due to pigments) that yellow and blue make green, have persuaded themselves that they can in a green see blue and yellow. (Sect. 238.)

124. *The Compound, and the Simple, Yellow.*—The yellow, produced from red and green, may be called the *compound yellow*. As has been already stated it is chromatically (but not optically) identical with the simple (spectral) yellow. It is possible to arrange two sets of absorbent

solutions, through one of which only red and green are transmitted, and through the other only the spectral yellow. By proper adjustment these two yellows may be made to match. But, place one set of media behind the other, and no light is transmitted, for each absorbs the light from the other. View the compound yellow through a red glass, and it appears red, through a green glass, green; whilst neither of these glasses alters the hue of the *spectral* yellow, except by darkening it. Instead of absorbent solutions we may use two glasses, the one coloured by aurine, which stops all blue and violet, the other by litmus, which stops out the yellow, the combination transmits only red and green, and appears yellow. If the red element in the compound yellow is weakened, the hue alters to greenish-yellow; if the green, to reddish-yellow. Increase the thickness of the medium, which transmits the compound yellow, and the colour becomes reddish; diminish the thickness, and it becomes greenish.

Solutions of the following substances, litmus, potassium bichromate, copper sulphate, and potassium permanganate, will be found suitable for experiments on the simple and compound yellow; and if placed in wedge-shaped bottles, the thickness can be easily adjusted. Through a combination of the two first, only red and green are transmitted; through one of the three last, only the simple yellow is transmitted. (Sect. 22.)

Solutions of chromic chloride and picric acid, superposed, give a good compound yellow in the transmitted light. In small thickness the superposed solutions are green, in large red, in medium yellow.

125. *Lord Rayleigh on the Compound Yellow.*—Lord Rayleigh has carried out some most interesting experiments upon the compound yellow. Pure spectral red and green light were used, and were oppositely polarised, by a double-image prism, before mixing. The mixed lights were viewed through a Nicol prism, which allows of exactly adjusting the

proportions of red and green, so as to make a yellow to match a given standard yellow. (Sect. 74.) The results will be given in Section 183.

It may be remarked that ordinary yellow pigments reflect all the spectral colours from red to green; they therefore give off a light containing both the simple and the compound yellow, and to this fact their brilliancy is due.

The following colour equation:—

$$50 \text{ red} + 50 \text{ green} = 20 \text{ chrome-yellow} + 8 \text{ white} + 72 \text{ black}$$

shows how the bright chrome-yellow has to be diluted with white and dulled with black in order to match the compound yellow made from red and green pigments by rotation. (Sec. 258.)

126. *Purple and Green.*—Purple is absent from the spectrum. It is made from the two end colours red and blue (or violet), and its complementary is green. Lord Rayleigh remarks on the difficulty of getting good greens. Good blues and reds are common. A substance, which cuts off the less refrangible rays, gives the former; one, which cuts off the more refrangible, the latter. But to get green, the substance must cut off the spectrum at *both* ends, leaving only the middle. Substances well possessed of this dual absorptive power are not very common.

127. *Small Colour change for considerable wave-length change in the bluish-green rays.*—In the ordinary spectrum it is curious to notice how a considerable difference of wave-length in the rays from bluish-green to blue is accompanied by only a small difference of colour sensation. Why this is so is not quite clear, but one peculiarity of the eye, which probably accounts for some of the difficulty we feel in discriminating between bluish-greens, will be mentioned in Section 180. (See also Sects. 9, 140, & 310.)

PART VI.—COMPLEMENTARY COLOURS.

128. *Definition of complementary colours. Spectral Hues.*—Any two colours, which by their union produce *white*, are called *complementary*, such are the spectral colours red and marine, orange and greenish-blue, yellow and blue, greenish-yellow and violet, green and purple (blue with red). Divide the colours of a spectrum into any two portions, then the colour, which is the sum of the colours of one portion, is complementary to the colour, which is the sum of the colours of the other portion. The white produced by the union of all the spectral colours is to the eye just the same as the white produced by the blending of two properly chosen spectral colours. In choosing two complementary colours from an actual spectrum it is found that one of the two must be more, the other less, refrangible than the green, to which no single spectral colour is complementary.

We may go further, and we shall find that *three* spectral colours may be so chosen as to give white, when united. If then two of these are combined we get a colour, which is complementary to the third. In the path of a spectrum place a screen with two parallel movable slits, and so adjust them that the beams of coloured light, passing through them and falling on a cylindrical lens, form a white by the union of their colours, then these two beams are complementary. By stopping the light through either we see what colour the other is.

129. *Complementary colours from polarised light.*—When a doubly-refracting substance, illuminated by polarised light, is viewed through a Nicol-prism, the colours seen are replaced by their complementaries, when the Nicol is rotated through a right angle.

If such a substance, so illuminated, is viewed through a double-image prism, corresponding parts of the two images present colours complementary to one another, and if the images overlap, white results. The colours are interchanged when the prism is turned through ninety degrees. An instrument constructed for showing the above phenomena is called a Schistoscope.

When a plate of quartz (of proper thickness), lighted by polarised light, is viewed through a double-image prism, two uniform images complementarily coloured are seen. As the polariser is rotated, these images go through a series of beautiful changes, their colours however always remaining complementary. This is easily proved by allowing two portions of the images to overlap; the overlap remains always white.

Only by using spectral colours, or those due to polarised light, can colours, which are *exactly* complementary, be obtained. The complementary colours reflected from pigments being impure, and not so bright as white, do not give perfect white, when mixed.

With a crystal of selenite I obtained the following complementary pairs; red and marine, orange and blue (slightly greenish), full yellow and full blue, greenish-yellow and bluish-purple, green and purple, puce and bluish-green. By viewing (through a second double-image prism) the two complementary images, produced as described, we get two pairs of complementaries, and, by rotating this second prism, we can diminish to any extent the intensity of the light in one of the pairs, and at the same time increase that of the light in the other pair. (Spottiswoode.) Experiments of this kind exemplify the subjects treated of in Sects. 132, 133, 190, 194, 195.

130.—*Circular Polarisation.*—It is remarkable how vivid a colour is obtained by striking out from white light just a mere fraction of its total of colours. (Sect. 17.) Place a plate of quartz (suitable for circular polarisation) between

two Nicol prisms, and view the coloured image through a spectroscope, a dark band will be seen crossing the spectrum and obliterating some very small portion of it. Remove the spectroscope, and we see the quartz vividly coloured with a colour due to the sum of the spectral colours, less the small part corresponding to the dark band. Rotate one of the prisms and we shall see the narrow band travel from end to end of the spectrum, obliterating the different colours in turn, and indicating the colour which is absent from the united colour, seen when the spectroscope is removed. With a double-image prism we shall see two spectra, each with a dark band, the two bands striking out colours which are complementary. When one spectrum shows a band in the green, the other will show a band in the red and another in the violet.

(For interesting developments of this subject the reader may be referred to Spottiswoode, "Polarisation of Light," Chap. IX.)

131. *Complementaries by coloured glasses, and rotating discs.*—Lights transmitted through yellow and blue glasses give very fair whites, slightly tinted, usually with pink. Coloured discs, well selected, give whites, which are slightly gray, the gray also being usually slightly tinted with some residual colour. As every colour has its complementary, it follows that there may be any number of whites, the true composition of which can be determined only by the spectroscope.

132. *Every colour has many complementaries, varying in tint or shade.*—To every colour there is a complementary, but to every colour there are also a number of complementaries. For example red is complementary to marine. Suppose that in a compound disc it is found that 65 marine with 35 red give a grayish white. We may reduce these to 39 marine and 21 red, and fill up the remainder of the disc (40 parts) with white gray or black, and the result on rotation will still be a gray of some sort. It follows then, either that

the marine, or the red, or both, may be mingled with white or black or gray in any degree, provided the ratio of the red to the marine is kept constant in the mixture. Not only then is red complementary to marine, but so also are a series of modified shades and tints of red, ranging from dark-red to light-red, also complementary to the same marine hue. Colours diluted with gray may be called "broken" hues. We may dilute both colours, and they will still be complementary. Citrine—a broken yellow—is complementary to slate—a broken blue; plum—a broken purple—is complementary to sage—a broken green, and so on.

133. *Luminosity of complementaries.*—It might be supposed that the luminosity, or apparent brightness, of colours which are complementary would be the same, but this is far from being generally true. Violet, which possesses only a low luminosity, balances greenish-yellow, one of the brightest of the spectral colours: blue also balances yellow—a much more luminous colour. Marine and red are about equal in luminosity; but to be truly complementary the marine must be the brighter. A dark marine is not the perfect complementary to a bright red. When working with coloured lights there is no difficulty in adding their luminosities, blue and green lights added will balance red light. But, with pigments, the case is different, so that to make a marine pigment balance a red, we ought to be able to increase the luminosity of the marine. This cannot be done, except imperfectly, by adding white to it. So also to make an ordinary purple pigment more truly complementary to a bright green, the purple may be diluted with white till its colour resembles the pink flame of burning cyanogen. So in a diagram pale pigments or tints are used to illustrate the fact that coloured lights, when mingled, produce a mixture of brightness equal to the sum of the constituent luminosities. See Section 72 on the luminosity of pigments.

134. *Methods of finding a complementary. By a double-image Prism.*—The polarised light method of studying complementaries will often fail to furnish us with the means of

ascertaining the complementary colours in many cases that are of practical importance. The colours of many pigments, browns, olive-greens, etc., are not to be found among those given by the schistoscope. Other methods must be used.

Suppose we wish to find the colour complementary to that of a piece of brown paper. The paper is placed on a black ground, and near it is placed a slip of bluish-green paper. The two are viewed through a double-image prism (Sect. 76), and are so adjusted that the images coincide. If the resultant colour is white, or rather, pure gray, the complementary has been found. If not, the colour of the second slip must be modified until this resultant colour is gray. It is well to have in the field of view a piece of pure gray paper as a guide. This method is not a very good one, for the prism greatly reduces the luminosity of the colours, and the alteration of the second slip is tedious. I find that burnt-sienna and blue-gray are nearly complementary.

135. *By reflection and transmission.*—The apparatus employed for mixing colours by reflection and transmission (Sect. 77) may also be used for finding complementaries. We search for a colour which, when combined with the given colour, will give a gray. The true complementary is that which gives a medium gray, when the apparatus is so arranged that half of the coloured light of each is thrown together. The method is rather tedious.

136. *By rotating discs. An example.*—A better method is to employ Maxwell's discs. Suppose the colour complementary to a dull brownish yellow is required. A disc is painted with this colour and is associated with a blue and a green disc, because we know from experience that the complementary colour will be some combination of blue and green. The three discs are then so adjusted as to produce by rotation a neutral gray, which is matched by adjusting a black and a white disc on the same axis. The colour equation obtained is: (the disc containing 100 equal parts), say,

$$41 \text{ brown-yellow} + 45 \text{ blue} + 14 \text{ green} = 24 \text{ white} + 76 \text{ black}.$$

The complementary of the brown-yellow is therefore a slightly greenish blue.

But it will be noticed that the complementary fills more than half the disc, and with the particular pigments used it was not found possible to produce a gray, when the green and blue, together occupied only half, or 50 parts. An excess of area of the complementary colour has to be used, which indicates that this complementary has not sufficient saturating power. The true complement must be produced from a blue and green, so chosen that a mixture of 50 parts of them produces a gray with 50 parts of the brown-yellow. (This example is from Prof. Rood.)

Another similar method is taken from Prof. Church. Required the colour complementary to a deep amber colour. Take discs of amber, blue, green, and white, and so adjust them that they give on rotation a gray. Let this be matched by another gray produced by rotating discs of black and white. Withdraw the amber sector and replace it by an equal sector of a gray, the same as the gray before produced. On now rotating the disc containing white, gray, blue, and green, we shall get a pale grayish turquoise, exactly complementary to the amber colour. (Sect. 285.)

For some pigments, such as carmine vermilion and the bright yellow paints, it is not possible to prepare complementaries sufficiently intense, sufficiently saturated, so that these pigments must be reduced by inserting a black sector, if we wish to obtain the proper complementary to them.

137. *Details.*—I obtained the following results by rotation. 40 carmine and 60 marine gave white (or gray); 35 vermilion and 65 marine gave a white; 50 greenish-yellow and 50 ultramarine (artificial) an almost perfect white; 47 green bice and 53 violet a white; 53 green bice and 47 purple nearly a white; 50 emerald-green and 50 purple a gray. Emerald aniline green and Hofmann's violet would not give a white, but a green, blue, or marine, gray, according to the proportions used. This shows that there is not enough red in this "violet," which is really a blue-purple.

It is interesting to compare simultaneously the two whites (or light grays) furnished respectively by a disc with 50 of gamboge and 50 of cobalt, and another disc with 50 of gamboge and 50 of artificial ultramarine; the former give a slightly greenish-yellow white, the latter a slightly pink white. (Sect. 100A.)

138. *Conditions.*—In the three methods, just described, the three following conditions must be fulfilled in order that the colours should be perfect complementaries of equal saturating power. First, the second colour must of course be of the proper hue to form a gray with the first colour. Secondly, this gray should be produced when half the quantity of light from one coloured surface is blended with half of that from the other. Thirdly, this gray, so produced, should be a medium gray, like that produced from black and white in equal quantities.

139. *The Complementary or Chromatic Circle.*—It is very convenient and instructive to prepare a series of colours, and to so arrange them on the circumference of a circle that those which are complementary may be at opposite ends of diameters. The chromatic circle (Plate IV.) thus made will be again referred to in Section 207 on Contrast, in which complementaries play an important part.

The following twenty colours, embracing ten complementary pairs, may be arranged round the circumference of the chromatic circle. Each colour in this list is immediately followed by its complementary. Red and marine, crimson and bluish-green, red-purple and emerald green, purple and green, purple-violet and yellowish-green, violet and green-yellow, violet-blue and greenish-yellow, blue and yellow, turquoise-blue and orange-yellow, greenish-blue and orange.

In practically constructing such a circle, the pigments are carefully chosen, and the circumference is painted with them at places, whose angular distances are determined by the wave-lengths of the spectral hues that the pigments most

nearly represent. As the intensity and the purity of the colours of pigments are very variable, such a circle will not be theoretically accurate.

140. *Complementary Pigments.*—The following pairs of pigments are good examples of complementary colours: crimson-vermilion and viridian with a little cobalt; cadmium-orange and cobalt-green; lemon-yellow and genuine ultramarine; greenish chrome and artificial ultramarine; slightly yellowish emerald-green and carmine with artificial ultramarine; violet (carmine with ultramarine) and lemon-yellow with green.

In the bluish-greens a change very slight to the eye demands a change, which seems disproportionately large in their complementaries; and this is well shown on the chromatic circle. (Sects. 9, 127, 215.)

141. *Complementaries by artificial light.*—Colours complementary by daylight are not necessarily so by gaslight. The deficiency of gaslight in blue and violet causes pigments reflecting rays of those colours to appear darker; and, besides this, the yellowish colour of the general illumination requires that the mixture of the complementary colours should also be a yellowish gray. Speaking generally, to make colours, complementary by daylight, become complementary by gas-light, the red element must be relatively diminished and the blue increased; but the fact that the gray produced is really yellow-gray causes exceptions to this statement. Similarly, to make colours, complementary by gaslight, appear complementary by daylight, we must reduce the blue element and increase the red. (Sect. 118.)

Subjective complementary colours will be considered in Section 211, etc.

PART VII.—THEORY OF COLOUR.

142. *Theory of Colour. Young, Helmholtz, Maxwell.*—The human mind cannot rest satisfied with a bare list of facts, it seeks to know causes, to find the thread upon which the pearls may be arranged in order. Wünsch, in 1792, was the first to suggest a theory of colour, similar to the one afterwards enunciated (1802-7) by the celebrated Dr. Young. Young's Theory, after long neglect, was taken up by (among others) the celebrated physicists Helmholtz and Maxwell, and to them it mainly owes its present important position. The reader is especially referred to Section 178A for recent observations made in connection with Young's Theory. I am by no means unaware of the fact that the Theory, though generally, is not universally, accepted. Its principal rival is Hering's Theory. (Sect. 188.) Both Theories have their strong and their weak points, which cannot however be discussed in an elementary book like this.

In Sections 143 to 178 Young's Theory, as usually given, is followed. It will be seen that Koenig's observations (Sect. 178A) would introduce some modifications. The phenomena of colour-blindness (Part VIII.), when they have been more thoroughly investigated, will probably furnish the key to the true Theory of Colour.

143. *Three Primary Colour-Sensations; red, green, blue (or violet).*—The following is a brief account of Young's theory of colour-perception. Each element of the retina is capable of receiving three different colour-sensations, or contains three different sets of nerves. One of these sets of nerves is specially sensitive to the long waves, and gives

rise to the sensation of *red;* another set responds most powerfully to the medium waves, and produces the sensation of *green;* the third is most strongly stimulated by the short waves, and originates the sensation of *blue* (or *violet*). But each set of nerves, though it responds most powerfully to its own special exciting colour, is also acted upon, but in a less degree, by the other two colours. The red nerves are most affected by red, less by green, still less by blue; the green nerves are most affected by green, and less by blue and red; the blue nerves most by blue, less by green, and still less by red.

Light, that is of a wave-length intermediate between the wave lengths of those particular colours, which most powerfully excite any two of the three primary sensations, will excite *both* sets of nerves, acting the more powerfully upon that set to which its wave-length is the more nearly related. (See Plate V. for intensity curves of the primary colour sensations.) If, then, we regard, as the physiologically approximately simple colours, those three which excite to the greatest degree the three fundamental sensations of red green and blue, it follows that all other spectral colours, though physically simple, are physiologically compound, for they are capable of exciting more than one of the primary sensations.

The Primary Colours will be those which are incapable of being compounded, but which, by proper compounding, will yield all other colours.

144. *Explanation of results in Colour-mixture, etc.*—It follows that if all three sets of nerves are equally and simultaneously stimulated, the sensation of white (or gray) will be produced, and this is easily shown to be the case, either by rotating discs of the three colours (red green and blue), or by combining the same hues by Maxwell's colour-box. The absence of all stimulation will correspond with the "negative" sensation—black. Unequal stimulation will give rise to positive colour.

If the red and green nerves are excited, yellow should result, and we have already had numerous examples of the production of this compound yellow. The yellow produced by the disc method is somewhat dull, because the red and green pigments stimulate also to some extent the blue nerves, so that some sensation of white is added to the yellow ; and the yellow pigments, with which we compare our compound yellow, are much brighter than the green and red from which it is formed. When the compound yellow is made from spectral red and green, we have still to contend with the dilution due to the excitation of some of the blue nerves, but good yellows are produced from orange-red and yellowish-green. When we look at the bright simple spectral yellow, we may assume that it excites powerfully the red and green nerves, producing very little effect on the blue, and so we get a very pure and luminous sensation of yellow. By altering the intensity of the red or the green we should expect to produce the colours between red and yellow or between yellow and green, and this we know to be the case. The colours between green and violet are produced by mingling green and violet in proper proportion, and this again falls in with Young's theory, as also does the fact that these compounded colours are whiter than their simple spectral representatives.

145. *Intensifying a Colour-sensation.*—With regard to the three fundamental colour sensations, it was mentioned that one supposition in the theory is that red light stimulates not only the red nerves, but to a slighter extent the green and violet also.

If this is so, it follows that we never get by ordinary means one colour-sensation excited purely by itself. Any red (even that of the spectrum) is mingled slightly with green and blue, and the result of this is to make it look as if a little white light had been added. (Sect. 192.) If we could remove the green and violet nerves from a portion of the retina we should get the full undiluted sensation of red.

Now by looking for some time at a surface coloured with a mixture of green and violet (or by wearing for a time greenish-blue spectacles), we can produce exhaustion of the green and violet nerves, and if now (after removing the spectacles) red is looked at, it will appear richer and fuller than it did before. Similar remarks apply to the sensations of green and violet. (Sects. 169, 221.)

146. *The Fundamental Colours.*—It does not appear to be quite settled whether blue or violet is to be taken as the third fundamental colour-sensation, but it will be simpler, on the whole, to take violet. The simple blue of the spectrum will then excite the green and violet nerves and so produce blue, a blue which will be more saturated than the compound blue produced by mingling green and violet, for there will be less excitation of the red. The reasoning is similar to that employed in connection with the simple and compound yellow.

147. *Further explanation.*—Green light, mixed with any other colour of the spectrum, produces a hue less saturated and whiter than the hue of the simple colour to which the mixture most nearly corresponds. This result follows from the theory, for green excites not only green, but also violet and red to a less, but an appreciable, extent. The median position of the green seems to enable it to stimulate the nerves which correspond to the more and to the less refrangible rays on either side of it. (Sect. 89.)

No mixture of coloured lights will produce a pure red or violet, and this again is in accordance with theory. (A whitish green is producible from yellowish-green and bluish-green.) The white, produced by yellow and blue, is easily accounted for, when it is remembered that, as yellow excites both green and red, we have all three sensations stimulated. Similarly for the white produced by red and marine, and other pairs of complementary colours.

148. *Two ways of exciting the same colour sensation.*—It is very important to remember that there are two distinct ways of exciting those colour sensations, which are not

fundamental; either we may use a simple spectral colour, or we may use a compound colour of the same hue as the simple spectral one. The eye is quite unable to reveal the way in which the colour is made, but the prism at once detects whether the colour be optically simple or compound. The judgment of the resemblance of two colours is determined, not by their physical identity, but by a cause residing in the eye. (Sects. 13, 14.)

148A.—Purple is the only compound colour which does not resemble any of the spectral colours. Produced from red and violet, it cannot be obtained quite pure, because the green nerves are slightly stimulated by both its components. It will be recollected that the colours of certain mixtures of spectral colours (Section 88, etc.), are not pure, but whitish, the reason being that there is, in addition to the special stimulation, a slight general stimulation, varying in amount according to the colours used. For ordinary eyes the law of colour-vision is the same, and a careful observer can determine the resemblance of colours with great precision.

149. *Triplicity in the eye, not in the spectrum. Tricoloriperception.*—Young was of opinion that the three primary sensations, red, green, and violet, were simple sensations, and that all other colour sensations were compound, when viewed from the subjective side, though (as we know) such colours, as are in the spectrum, are objectively simple. The hue of a colour then will depend upon the proportion of the intensities with which it excites the three fundamental sensations, and its brightness will depend upon the sum of those intensities. The triplicity assumed is not in the light itself, but in the colour-sense. The Primary Colours are to be sought, not in the nature of light (in the spectrum the only differences are those due to wave-length and intensity), but in that of man. Colour exists only in the eye, not outside it. Colour-vision is a part of Mental Science, investigated by optics and physiology. As the theory postulates three sensations, we may speak of normal vision as "tricoloriperceptive."

150. *Maxwell on the Theory of Colour.*—Prof. Maxwell puts the problem of the theory of compound colours very succinctly. [The investigation of the chromatic relations of the rays of the spectrum must be founded upon observations of the apparent identity of compound colours as seen by an eye, either normal or abnormal; and the results must be regarded as partaking of a physiological as well as of a physical character, and as indicating certain laws of sensation, depending upon the constitution of the eye, which may differ in different individuals. We have to determine the law of the composition of colours in general, to reduce the number of standard colours, to which all colours may be referred, to the smallest possible, to discover what these standard colours are, and to ascertain the relation which the homogeneous light of different parts of the spectrum bears to the standard colours.]

151. *Prof. Stokes on Young's Theory.*—Professor Stokes —probably the greatest living authority upon light—has the following interesting remarks in his recent "Burnett Lectures." [Assuming three primary colours, the difference between them may be subjective or objective. If objective, there would be three kinds of light usually mixed together in any light presented to us, each kind affecting us with the same sensation as to colour, a sensation different from that with which the other two affect us. If subjective, we might have three senses in relation to light, so that if one alone were affected we should have as to colour a particular sensation, which would remain the same, though other circumstances, such as the refrangibility of the light, might alter. On the former supposition an element of a pure spectrum would contain three kinds of light (though not separable by refraction) the proportions of which would change from one part of the spectrum to another. On the latter, the light of an element would be homogeneous, but would be capable of exciting our colour senses simultaneously, but in proportions differing according to the place of the element in the spectrum.

Of these two suppositions, the second is by far the simpler. For, even if there were a triplicity in the object, we should still require a triplicity in our organization in order that the objective difference might be subjectively perceived as a difference; whereas, if a triplicity in the organization be admitted, we have no need to assume in the object a triplicity of which we have no experimental evidence. Brewster thought he had succeeded, by the use of absorbing media, in modifying the tint of a given part of a pure spectrum, but he was mistaken. There is no proof that light, homogeneous as to refrangibility, is nevertheless heterogeneous as to colour. There is no evidence of objective triplicity in the spectral element. The experiments of Helmholtz and Maxwell appear to show that the existence of three primary colour sensations suffices to account by their union for the various colours we perceive. Maxwell has shown that if we take three standard colours X, Y, Z, any colour C, may be expressed by the formula:

$$C = a\,X + b\,Y + c\,Z,$$

where a, b, c, are numerical coefficients, which may be positive or negative; (=) means matches in colour and intensity; (+) means superposed on, and (−) means that, in the case of a negative coefficient, the term must be transferred to the other side of the equation.

If the standard colours are well chosen, a, b, c, will in most cases be positive. The best standard colours appear to be red green and blue. Hitherto microscopic observation of the mammalian retina has not revealed any difference of structure suggestive of a triplicity of function. But in the retinas of birds and reptiles the inner limbs of the cones of the retina are furnished with brightly coloured globules, the use of which may be connected with the colour-sense.]

152. *The Visual Purple.*—In most vertebrates the outer limbs of the retinal rods are suffused with a colouring matter called the Visual Purple. This turns yellow and then white under the influence of light, but in the dark the purple is

reproduced. What bearing these photo-chemical facts have upon colour-vision is not yet known. It is possible to photograph on the retina by means of the bleaching action of light upon the visual purple, and in this way optograms have been obtained. Is it possible that the visual purple is the cause of the purple colour seen in the experiment described in Sect. 187 ?

153. *Lord Rayleigh on the Theory of Colour.*—Lord Rayleigh puts the theory of colour concisely thus : [It is known that our perception of colour is threefold; that is, that any colour may be regarded as made up of definite quantities of three primary colours, the exact nature of which is however still uncertain. More strictly stated the fundamental fact in the doctrine of colour is that, between any four colours, given as well in quantity as in quality, there exists a linear relation. Two of them can be so mixed as to match a mixture of the other two, or else one of them can be matched by a mixture of the other three. The experimental and theoretical results agree within one quarter per cent.

With the colour discs the necessity for filling the entire circle requires us to add black sometimes, and we may then say that, with any four colours and black, a match can always be made.]

154. *Further remarks on the Primary Colours.*—The exact selection of the colours corresponding most nearly to the three primary sensations is not easy. Maxwell selected a red between C and D, a green between E and F, and a blue between F and G. Helmholtz prefers violet to blue. All other hues may be produced by combining in proper proportions the primary colours, provided that we can also dilute them and darken them.

Maxwell also states that the only data at present existing for determining the primary colours are derived from the comparison of observations (e.g. colour equations) made upon normal and colour-blind eyes.

If a spectrum be thrown upon a white screen in a room not well darkened, we shall see, at a casual glance, red, green, and violet-blue, the very colours chosen by our theory. Another way of seeing the primary colours is to look through a prism at a white strip upon a black ground. (Sect. 157.)

155. *Primary and Secondary Colours.*—Taking red green and blue as *primaries*, the colours produced by combining any two of them may be conveniently called *secondaries;* these will therefore be yellow marine and purple. Any secondary is of course complementary to the primary it does not contain. (Plate IV.)

The secondaries can be seen by looking through a prism at a black strip upon a white ground. The fact that yellow is producible from red and green removes it from the list of primary colours, among which it is still so often placed.

Usually the term secondary colours is confined to those colours which result from *equal* stimulation of two primary sensations, and they are those given above—yellow, marine, purple. But some authors include in the term all colours produced from two primaries, in whatever proportion these may be combined. In this case we should have to add the colours between red and yellow, those between yellow and green, those between green and marine, those between marine and violet, and the various purples produced by violet and red when unequally combined.

The secondary simple spectral colours are as a rule richer than those made by combining the primaries, for these compound secondaries usually contain some white light, due to stimulation of all three of the primary sensations.

For further remarks on secondary colours, see Sect. 158.

156. *Tertiary Colours.*—Tertiary colours, or *Tertiaries*, are usually considered as resulting from a mixture of the three primaries, or of a secondary with the primary it does not contain. The perfect tertiary is white, and no other tertiary really exists. For it is evident that any mixture of

the three primaries, not in the proportion to give white, may be viewed as consisting of white coloured by the primary or secondary left after subtracting the colours which make white. We get a primary or secondary of a paler tint, that is all. Russet is a reddish gray, citrine a yellowish gray, sage a greenish gray, and so on. (See Sect. 159.) By mingling various colours with gray by rotation, or some other method, we obtain an interesting series of *dulled* colours, which can be made to imitate some particular obscure tint, and thus reveal its composition. Nature abounds in colours which may be represented by some primary or secondary mixed with more or less of white black or gray. (Sects. 132, 236, 285, and Part XII.)

157. *Brewster's Theory. Red yellow and blue as Primaries.*—Other theories besides Young's have been suggested. In the well-known theory, to which Brewster gave his support, red yellow and blue are taken as the Primaries. It is still largely adopted by artists and writers on art, yet Brewster's view of the existence of three overlapping coloured tracts (red yellow and blue) in the spectrum is incompatible with the simple character and definite refrangibility of every ray of the spectrum, with the subjective character of the sensation of colour, and with experimental investigation. (Sect. 151.)

158. *Secondaries (Brewster).*—According to this theory the Secondaries are orange (red and yellow), green (yellow and blue), purple (blue and red). Now it is true that by mixing paints these secondary colours can generally be obtained. In fact, for the purpose of producing colours by mixture on the palette, red yellow and blue are better than red green and blue. We cannot make yellow from the latter by palette mixture, whilst we can make green from the former.

But it has been explained that these palette colours result, not from a true mixture of the lights, but from survivals after absorption. Most red and all yellow paints transmit

orange, most blue and all yellow paints transmit green, and many blue and red paints transmit both blue and red. The orange obtained by mixing pigments is a fairly good one, but the green and purple are dull colours generally. (Blue and green paints give a dull marine, when both of them transmit blue and green, as is generally the case). Sects. 269, 274.

159. *Tertiaries (Brewster).*—The Tertiaries on this theory are supposed to be made by mixing the three primaries, or a primary and its complementary secondary, in such proportions as to give, not gray, but a coloured mixture. But, even on this erroneous theory, the tertiaries obtained would be, not new colours, but simply primaries or secondaries modified by gray.

Buff is a grayish orange, plum a grayish purple, slate a grayish blue, and so on.

Although these tertiary tints have not, even by Brewster's theory (when rightly viewed), the nature of *new* colours, still they are of very great value to the artist. (See also Part XII.)

160. *Artists and Brewster's Theory. Complementaries.*—The fact that artists have for centuries been accustomed to produce colours by mixing pigments, a process for which Brewster's theory gives fairly correct results, is doubtless the reason why it has so long held the field. Chevreul, the Nestor of French Savants, and author of a standard book on Colour, made this theory the foundation of his elaborate researches.

Upon Brewster's theory orange, green, and purple, are the colours complementary to blue, red, and yellow, respectively; but experiment demonstrates that pairs so chosen do not make white. We have seen that yellow, marine, and blue, are theoretically the true complementaries, and, later on, we shall find that this is also artistically correct. (Sect. 223.)

161. *Goethe's Theory of the Dim Medium.*—Many years ago Goethe propounded a theory of colour, of which he is said to have been prouder than of "Faust." It may be called the Theory of the Dim Medium. Dark objects, seen through a dim medium, look blue, bright ones, red. In Sections 46 and 47 the production of colour by turbid media was explained, and this is really the basis of Goethe's theory, which has now an interest only historical.

But the received (Young's) theory is not free from difficulties, and it may be modified with the advance of knowledge. (Sect. 142.)

PART VIII.—COLOUR BLINDNESS, AND VARIATIONS IN COLOUR-PERCEPTION.

162. *Sensations cannot be exchanged, but the majority appear to agree.*—Although we cannot exchange sensations, it appears to be certain that the vast majority of persons experience practically identical sensations of colour. They will arrange and classify tints and shades of colours in the same order and in the same groups. Such mistakes as are made will be due to imperfect training, or to a slight lack of sensitiveness, or to a want of definite nomenclature. The experience of the majority then determines what we may call the normal classification of colours. (Part XI.)

163. *Abnormal colour-vision.*—But there are numerous cases of abnormal or imperfect colour-vision, varying both in kind and in degree, and found more frequently in men than in women. Clear cases of colour-blindness are those in which the colour-blind person is unable to discriminate colours, which to the ordinary observer are quite distinct.

164. *Red-blindness.*—By far the most common case is a more or less defective sensation of red. Dr. Dalton was afflicted with this red-blindness, hence sometimes called Daltonism. To red-blind persons red and green may differ, not in hue, but only in shade. The cherry and its leaves may differ in form, not in hue. The spectrum presents only two colours which are called by red-blind persons yellow and blue. The extreme dark red is to them invisible. The spectrum begins to be visible about line C, and the colours

from red to green appear as various tones of yellow, with a maximum brightness between the lines D and E. Near the F line, where the hue to the normal eye is marine, there is a zone of neutral gray ; and beyond this the tones of colour are blue, with a maximum brightness between F and G. To red-blind people, coloured objects may appear somewhat as they would to the ordinary eye, if viewed through a marine coloured glass, transmitting blue green and yellow, or if illuminated by a light containing the same colours.

165.—*Bicoloriperceptive Vision.*—These appearances may be fairly well explained by assuming that this variety of abnormal colour-vision is bicoloriperceptive, the nerves for red being either absent, or if present, transmitting the same sensation as the green nerves (but this is doubtful) ; whilst the blue nerves are about the same as in the normal or tri-coloriperceptive eye. The neutral zone of gray may be assumed to be due to the simultaneous excitation of blue and of the colour which the colour-blind call yellow ; for in a bicoloriperceptive eye the excitation of the two colour sensations would produce the same sort of effect as that of the three in a normal eye. (Sect. 261.)

166. *Maxwell on Colour-blindness.*—Maxwell found that he was able, with red-blind people, to produce matches of any spectral colour, by combining two coloured discs and a black disc, whereas the normal eye requires three coloured discs and a black disc. Also with his colour-box he found that only two spectral colours (blue and green) were necessary to produce a colour chromatically identical with white.

He obtained the following equations, first for a colour-blind person :

$$34 \text{ green} + 33 \text{ blue} = \text{white}.$$

Then for a normal eye :

$$26 \text{ green} + 37 \text{ blue} + 23 \text{ red} = \text{white}.$$

167.—Combining these equations we get

$$23 \text{ red} + 4 \text{ blue} - 8 \text{ green} = D.$$

D is the missing colour, and resembles a full red, from which 8 of green have been subtracted, and to which 4 of blue have been added.

168. Another equation for a colour-blind person was :

$$19 \text{ green} + 5 \text{ blue} + 76 \text{ black} = 100 \text{ red},$$

so that a dark bluish green looked the same as a full red. Two colours, which match to a colour-blind eye, can differ to the normal eye only by the degree in which they excite the sensation missing from the defective eye.

In a colour diagram these two colours will lie upon a line passing through the position of the missing colour. By determining two such lines their intersection will locate this position. A line, drawn through this point, and through the position of white, is, to the colour-blind, the line of *neutral* hues, passing from black through gray to white. (Sect. 261.)

169. But red-blind persons can easily be enabled to distinguish red from green, for through a red glass the former looks brighter than the latter, whilst through a green glass the reverse is the case.

If we wear a pair of bluish-green spectacles (the glass being of a kind which transmits both green and blue) we may assimilate our vision to that of the red-blind. But, on removing the spectacles, the eyes will be abnormally sensitive to red, and will give us a most vivid red sensation on looking at a red object. Also, if we wear red spectacles for some time, and then remove them, the red nerves will have been exhausted, and our perception of colours will again be similar to that of a red-blind person. (Sect. 145.)

170. *Percentage of persons colour-blind.*—It has been estimated that about one male person in eighteen is more or less red-blind. One estimate, made in France in 1874 among railway men, gave nine per cent. as the proportion of colour-blind persons. Prof. Holmgren, in 1876 in Sweden, found about five per cent. among the same class of men. The

statistics of the Ophthalmological Society show that of 14,846 males, 4·16 per cent., and of 489 females, 0·4 per cent, were colour-blind. From this it follows that the defect is ten times more common in men than in women. Mr. Galton, from experiments made at the International Health Exhibition in London in 1884, obtained results agreeing pretty nearly with those of previous observers.

That the defect is more common in men than in women, is a fortunate thing, as varied colours are used so largely in women's garments. Possibly, on the Darwinian Theory, a more delicate perception might be expected as a result of sexual inheritance. In Quakers the percentage of the colour-blind is said to be above the average. Both railway men and sailors are now always carefully tested, as mistakes between red and green might result in very serious accidents. The physician, chemist, tailor, milliner, etc., are heavily handicapped if colour-blind. There is evidence that the defect is often hereditary. I am acquainted with two pairs of brothers who are colour blind.

171. There has been a difference of opinion as to whether red-blind persons see the red-to-green part of the spectrum as yellow or as green. Professor Holmgren—one of the best authorities—gives his verdict in favour of yellow. (Sect. 175.) The confusion of the pigment colours green and yellow, orange and red, purple and blue, red and blue-green and gray, is (he says) well explained on this supposition.

172. *Violet-blindness.*—Besides red-blindness there are said to be cases—much rarer however—of blindness to violet (or blue), and to green. The violet-blind person would probably see, in the spectrum, red up to about the yellowish-green part, and then a narrow neutral zone of white, followed by a green gradually darkening until it stops altogether about line G. Such persons may confuse the pigment-colours green and blue, purple and red, orange and yellow, violet yellowish-green and gray. (Holmgren.)

173. *Green-blindness.*—Green-blind eyes (it is said) may confuse purple with gray, and blue with blue-green. These phenomena of colour-blindness throw a good deal of light upon the theory of colour we have already discussed, and do much to strengthen it.

174. *Abnormal Colour-discrimination.*—Professor Church gives an interesting account of a colour-blind person by whom two green solutions (nickel chloride and acidulated copper chloride) identical to the ordinary eye, were at once recognised as different. The green colour was in each case complex. To normal vision the sum of the colours in each case gives a sensation of green. To the defective eye, one at least of the colours transmitted by one of the solutions was not normally perceived, and hence the differentiation between the two solutions.

I tried these solutions (identical to my eyes) with H. F. (Sect. 178.) He called both solutions green, but had no difficulty in distinguishing between them, and said the nickel was darker than the copper. After careful spectroscopic examination of the two I can scarcely find any difference in the transmitted rays, though the nickel cuts off rather more of the red than does the copper. The only colours absorbed are the outer violet and the outer half of the red.

The deficiency of gas-light in blue causes ordinary blues (which reflect both blue and green) to look greenish to the normal eye, and makes it difficult to discriminate between certain blues and greens. By gas-light also we naturally regard yellow as white, and so set up a false standard. (Sects. 116-8.) In a room, lighted by a monochromatic light, we are all of us practically colour-blind. (Sect. 110.)

175 *Favourable Cases.*—The naming of colours by colour-blind persons is of course useless for comparison with the normal naming, because colour is a subjective phenomenon. So the statements that to a red-blind person yellow is yellow, blue blue, red dark gray, orange brown, purple

slaty-blue, green gray, and so on, are in themselves worthless. To really get at a comparison between the colours as seen by the red-blind and by the normal eye, we must find a person who has one eye red-blind and the other normal. Fortunately such a case has been found, and the result is that, for a red-blind person, the red-yellow-green part of the spectrum is yellow, the blue part blue. The method of experiment is to present to the normal eye colours to be matched by other colours seen only by the abnormal eye. Might it not be possible to imitate to some extent such cases, by putting a coloured glass in front of one eye, or by exhausting one eye for a certain colour?

176. *Dr. Roberts on Colour-blindness.*—Dr. C. Roberts states that it is impossible to draw a line between colour-blindness and colour-ignorance. Some people have a very keen appreciation of minute differences of tint or shade, others can distinguish colours broadly, but are puzzled by various shades or tints of the same colour, others again are really colour-blind. Education can do a good deal towards removing the confusion due to ignorance of the names and mutual relations of colours.

177.—Red-blind people appear to confuse the colours marine, pale green, pink, gray, and light brown; red, green, and brown; blue, and purple. There appear to be cases (very rare) of total colour-blindness. In these I suppose all hues would appear as white, gray, or black, so that a picture would resemble its photograph. But it is possible that there is one colour-sensation remaining, and it may correspond with blue. The matter could only be settled by getting a person with one eye normal and the other unicoloripercep-tive. (Sect. 175.) A dose of santonine is said to produce temporary blindness to blue and violet.

178. *Further observations.*—A Cardiff friend kindly allowed me to make a few experiments, and from them I infer that he is more or less colour-blind to red. A blue and green, mixed by rotation, appeared to him to match a

gray. Pale carmine and aniline emerald green looked nearly alike. Blues purples and violets were classed together as blues, reds and yellows were classed as yellows. The spectrum appeared yellow and blue with a neutral zone of gray between. By gas light he considers he can discriminate certain colours, which appear almost alike by day light.

From a Newport friend (Mr. B.) I obtained the following results. The spectrum (a long one produced by a bisulphide of carbon prism) was seen by him in nearly its whole extent, except for a small part of the extreme red. The portion, from red to green, he called "yellow;" the portion, beyond the green, "blue." I could not make out that he saw a neutral tint at the meeting of the "blue" and "yellow." Yellow papers were correctly sorted. Blue and purple papers were classed together as "blue." A marine tinted paper he could not name. Pale brick red and yellowish Hooker's green were placed together; so also were dark green and dark red; and emerald green, chrome green, orange, red lead, burnt sienna, and olive green. An orange colour more nearly resembled an emerald green than it did a good red. Blue and magenta-purple films of gelatine were both called "blue." The former transmitted no red, the latter a great deal of it. An emerald green paper and an orange one, which were nearly alike to his naked eye, were at once discriminated on looking at them through the magenta film, the green appearing nearly black. To me the green, under these circumstances, is a dull violet, and the orange is scarlet. On holding the magenta film so that the orange only was seen through it, whilst the green was seen with the naked eye, Mr. B. said that the papers looked almost exactly alike. If this is so, it appears that the film does not, in the case of Mr. B., cause much change in the orange paper, a result I should not have anticipated.

Placing before my eyes two superposed glasses, one blue the other green, I find that my vision is somewhat similar to that of Mr. B. (The conjoint glasses have a marine

colour, and transmit dull red, yellowish-green, green, and blue.) I easily sort out yellows and see them as yellow. Reds and dark greens look somewhat alike. Marine looks gray. Blues and purples are blue. Emerald green looks a greenish gray, and light red also a gray. A magenta film seems dark blue.

A brother of Mr. B. is also colour-blind. With the spectroscope he sees only what he calls "yellow" and "blue." A magenta film and a blue film are both "blue," the former a little the darker. A coffee-brown paper and a dull green are exactly alike. Pink and bluish-green, yellowish-green and red-lead, olive-green chrome-green and umber, are placed together. Blues and purples are called "blues." Yellows are correctly sorted and named. Orange and emerald-green are somewhat alike, but look more alike when the orange is viewed through a film of gelatine coloured with magenta, the green being viewed directly.

H. F. (a boy, age 13 years, of very dark complexion) is colour-blind. The spectrum is "yellow" and "blue." The yellow extends into the red, but not quite so far as I can see red. The brightest part of the spectrum is the yellowish green. A magenta film is a "blue" rather darker than a blue film. (This magenta film transmits only red and blue, whilst the blue film transmits only green and blue). One thickness of a red glass (transmitting besides red only a little orange) looked the same as three thicknesses of a green glass (which transmit yellow green and a little blue). But the red and green glasses were at once discriminated on looking at them through a green or a red glass, as in the first case the red, in the second the green, was darkened.

With coloured wools he placed together, as "pink," the pink pieces, the yellow-green and medium green as "green," the blue and purple as "blue," the yellow and orange as "yellow," the marine as "gray," the dark green, medium red, and dark red, alike as "red." With coloured papers he placed together as alike, scarlet and deep green, emerald green and light brick red, pink and bluish green, red lead

chrome green olive green and scarlet, umber and burnt sienna, coffee-brown and dark green; these last two being "exactly alike." Yellows and oranges were "yellow," blues and purples "blues." Dull green and drab were alike, except in shade. A crimson and a dark green were called "browns," and a dullish green was a lighter "brown." With rotating discs, the pair, 70 emerald green and 30 cobalt blue, matched a gray, made of 30 white and 70 black.

Testing by coloured solutions seems to me to be more satisfactory than by coloured papers, for in the former the colours transmitted can be definitely ascertained by the spectroscope. The following results were obtained from H. F. with coloured solutions. He placed together as "yellow," light yellow picric acid, light yellow potassium chromate, orange-yellow aniline, and green-yellow fluorescin; and to him the chromate and the aniline were the two most nearly alike. To me the aniline is decidely more orange than the chromate, which I should place with the picric solution. As "dark yellows," he placed together orange potassium bichromate, orange aurine, orange aniline, erythrosin (red-orange with a touch of purple), mixed potassium bichromate and copper sulphate (slightly yellowish green). To both of us the aurine and the aniline are the two most alike. The yellowish-green solution, to F., resembles the erythrosin, but is "darker." To ordinary vision the contrast is of course startling. As "reds," he classes together deep red strong magenta, and deep red-purple potassium permanganate. (By the spectroscope, I find that both these solutions transmit practically only red, and though a little blue gets through the latter solution, they are both too strong to appear purple.) Olive-green chromic chloride, greenish-blue chrome-alum, and bluish-green emerald aniline green, are classed together as "browns." Crimson ferric sulphocyanate, aniline scarlet, grass-green chlorophyll, mixed ammoniacal copper sulphate and potassium bichromate (full deep green), mixed chrome-alum and potassium bichromate (brown orange), are placed together as more or less alike, but are

not named. The copper and the chlorophyll are the nearest alike, and in this my vision agrees, but the other three solutions are of course quite different, not only from the foregoing pair, but also interse. As "blues," he placed together medium blue indigo, deep violet-blue aniline, violet-blue ammoniacal copper sulphate, purple aniline, purple litmus, light blue copper sulphate, and light blue copper chloride. The two most alike are the last pair, and in this I agree; but I should at once separate the purple aniline and litmus from the blues proper.

For the results of spectroscopic examination of the above solutions, see Sect. 17A.

178A. *Koenig on Young's Theory.*—A most valuable contribution to the Theory of Colour-vision (by Dr. Arthur Koenig) will be found in the Brit. Assoc. Report for 1886. A short summary is given here.

The investigation begins with the reduction of the infinitely large number of colour-sensations to the smallest number of elementary sensations, which by their intensity and mutual relation produce every possible kind of colour sensation. This is an experimental problem quite independent of hypothesis. It is a fact that in every individual every sensation of colour he can experience can be produced by spectral lights and their mixture. A "curve of elementary sensation" is a curve which determines the intensity of elementary sensation for light of any given wave-length.

The apparatus used was similar in principle to, but more elaborate than, that described (in Sect. 74) as used by Lord Rayleigh. Two pairs of spectra were formed, the two lights of each pair being oppositely polarised, so that, in any mixture of two colours from either pair, the ratio of the components could be exactly adjusted. The apparatus allowed of comparing together monochromatic light with monochromatic, a mixture of two colours with a monochromatic light, and two such mixtures. A very large number of colour-equations (Sect. 104) was obtained from the people examined.

Results: (1) There are persons, very few in number, who can distinguish no different shades of colour, and to whom a colour picture will appear as a photograph does to us. The curve of elementary sensation H, for this unicoloriperceptive vision is given in Plate V., Fig. 1. It has a maximum of intensity near the fixed line *b* in the colour which, to a normal eye, is a somewhat bluish-green.

(2) There is a second numerous class of persons, generally called colour-blind, in whose case we can divide the spectrum into three parts, two "boundary regions," one at either end, and an "interval" between. For these persons each boundary region has its own light, varying in intensity, but not in colour, and the colour of any part of the interval can be produced for them by a mixture of the light of two parts, one from each boundary region. Here we must assume *two* elementary sensations, and we assume the sensations of the boundary regions to be these. (See Plate V., Fig. 1.) The curve K (with a maximum between F and G in the blue) was obtained for all the people of this second class; but the other curve varied, some having the curve W_1 (maximum in the yellow), others the curve W_2 (maximum in the yellow-green). So there are two types in this class. So far then the colour-blind (usually so-called) appear to be divisible into two classes only, the unicoloriperceptive and the bicoloriperceptive, the latter having two types.

(3) There is a third very large class, also containing two types, the normal and the abnormal type, and this class includes the majority of people. If for this class we assume *three* elementary sensations, so that their vision is tricoloriperceptive, all colour equations made by them are accounted for. The persons of the second type of this class are much smaller in number than those of the first type, and in fact are not more numerous than those comprised in class 2.

A person of this third class finds in the spectrum two boundary regions, one at each end, and we assume that the colour-sensations given by these are elementary. The parts from the boundary regions to a certain distance

towards the middle of the spectrum are the boundary intervals, and the remaining part is the central interval. The colour-equations show that in each of the two boundary intervals we must assume two elementary sensations, one of which is the same for both, whereas the other is the elementary sensation of the adjacent boundary region. Lastly any colour of the central interval is the result of the three elementary sensations already found, R, G, V. (Plate V. Fig. 2, normal type.) It will be seen that R has a maximum in the yellow, G in the yellowish-green, and V in the blue.

The analysis of colour sensations having been completed without any hypothesis, it remains to be seen whether we can draw any inference as to the physiological process which produces the sensation of colour. A sensation which is caused by a simple process at the terminal of the optic nerve is called a *fundamental* sensation. It is evident that for every person the number of fundamental sensations is equal to the number of elementary sensations, and that we can speak of curves of fundamental sensations. All colour equations are linear and homogeneous, and since both the elementary and the fundamental sensations are the solutions of these equations, it follows that the fundamental sensations of every person must be homogeneous linear functions of his elementary sensations.

Hence, if the fundamental sensations are denoted, in the first type of the second class, by (W_1) and (K_1), and those, in the normal type of the third class, by (R), (G), (V), we get

$(W_1) = a\ W_1 + b\ K_1$ where $a + b = 1$, and $(R) = c\ R + d\ G + e\ V$, where $c + d + e = 1$, and so on.

By means of these equations curves are constructed, having the same relation to fundamental sensations as the former curves had to elementary sensations. Neglecting the first class (which is extremely small), and the abnormal division of the third class, it was found that curves could be

constructed such that persons, of the second class, have *two* such curves, and persons, of the normal type of the third class, *three* such curves. (Plate V., Fig. 3.)

The curves R, G, of the third class, are respectively identical with the curves (W_1) and (W_2) of the two types of the second class, the curve (V) is identical with the curve (K) of the two types of the second class.

Now, how does the colour-blind person of the first type of the second class see colours ? Here we must fall back on those rare cases (Sect. 175) where the same person belongs to this class with one eye, and to the normal type of the third class with the other eye. Such a person stated, that, while blue was the same to both eyes, the red-yellow-green part of the spectrum appeared yellow. For this class of the colour-blind then the supposition is that they possess, with the normal eye, the sensation V ; but that what are separate sensations R, G, in the normal eye, are with them compounded together into a colour corresponding with the yellow of the normal eye. The curve (G) has so far altered its form as to coincide with (R), and the sensation belonging to this curve is a resultant of the sensations belonging to (R) and (G), that is a yellow. The first type of the second class is therefore a *special* case of the third class.

The abnormal type of the third class (to which belong the cases referred to in Sect. 183) is considered by Dr. Koenig to be a transition type between the normal type of the third class and the first type of the second class, just referred to, as being a special case of the third class.

Dr. Koenig draws the general conclusion that Thomas Young's theory of colour-vision, slightly modified by modern research, is perfectly correct.

Dr. Koenig is also of opinion that in the bicoloriperceptive eye it is not the fibres for the perception of the third colour (the red-seeing or green-seeing fibres) that are wanting, but that these two sets of fibres are, so to say, differently tuned ; tuned down in those who are green-blind, tuned up in those who are red-blind.

179. *Variable sensibility of different parts of the retina.* In ordinary eyes the region of most distinct colour-vision is the centre of the retina, the *fovea centralis* of the yellow spot. As an object looked at is so moved that its image falls upon parts of the retina further and further from the centre, the colour gradually disappears. Red is the first colour to vanish, blue the last. (But see Sect. 180.) According to Woinow all distinction of colour ceases in the outermost part of the retina, and there remain differences of brightness only.

180. *The Retinal yellow spot.*—The *macula lutea* (retinal yellow spot)—the region of most distinct vision—is tinted yellow, and is found to exercise a selective absorption upon the bluish-green or marine rays, between the spectral lines E, F. In man the visual purple does not extend into the yellow spot.

If a white surface be viewed through a solution of chrome alum, a rosy patch will be seen in the neutral tinted field. The solution transmits red and marine, the marine colour is absorbed by the yellow pigment of the spot, which consequently appears as a rosy patch. Dark people see this spot more easily and also more strongly tinted than do fair people, but the effect of it, though varying in degree, is similar in kind. In fact, when looking directly at objects we see them as if through peculiar spectacles absorbing some of the marine coloured light. Maxwell had the yellow pigment so strongly developed that for him the marine portion of the spectrum was distinctly darkened. Is it owing to the variable depth of this pigment that colour-matches, made by different people, exhibit slight but constant differences in the proportions of the colours used? According to Maxwell the effect of the yellow spot is more marked in the red-blind eye than in the normal eye, the dark spot it produces being well seen in the neutral zone near F. (Sect. 183.)

Helmholtz says that the yellow spot is less sensitive to *weak* light than are other parts of the retina. That feeble lights tend to blue may be a reason for this. Faint stars are often better seen if received somewhat obliquely.

181. *Yellowing of the eye-lens.*—Occasionally the lens of the eye becomes tinged in old age with a yellow colour, which produces remarkable effects upon the appreciation of bluish colours. Mulready's later pictures are often spoken of as too cold, too blue, in tone; but, if they are viewed through a yellow glass, they at once assume a natural appearance.

The light reflected from pigments is so feeble, compared with that from external nature, that the effect of the yellow lens was only felt in the *painting;* there was no compensatory effect. For the same reason, Mulready's earlier pictures became less and less satisfactory to him, for he viewed them through lenses growing yellower, and yet not sufficiently altered to produce much change in *natural* objects. We easily see why, as time went on, he continually increased the proportion of blue.

182. The reason why white light does not appear tinted by the absorbent action of the yellow spot is that this action is *constant*, and that we reckon as white the mean of all the colours we are accustomed to see. If we wear strongly coloured spectacles for some time, we shall still call white objects white, though the rays which enter the eye are coloured. We can mentally allow for the influence of the coloured medium, through which objects of known colour are viewed. (Sect. 211.)

183. *On matching the compound yellow.*—In the experiments (referred to Sect. 125), Lord Rayleigh found that different observers varied sometimes a great deal from one another in the proportion in which they mixed red and green, in order to match a fixed yellow. In one case it was found that one person required only half as much red as another, in order to change a given amount of red into green. Lord Rayleigh does not give any explanation of this peculiarity, but remarks that it is quite distinct from colour-blindness. It has occurred to me that the peculiarity may

be due to the variable depth of colour in the pigment of the yellow spot. (But see Sect. 178A.) (The original paper should be referred to; *Nature.* 17 November 1881.)

184. *Haidinger's Brushes.*—In connection with the yellow spot, a brief reference may be made to Haidinger's Brushes. On looking at a beam of plane-polarised light, most persons can see a bright yellow double cone or brush, crossed by a similar figure of a complementary violet colour. The appearance is only transitory, and seems to be more readily seen by people of dark complexion, who have the yellow spot well coloured. Maxwell showed that the brushes are well seen in connection with the macula lutea, being due to some peculiar structure of this part of the retina, which enables it to polarise light. As Maxwell puts it, the brushes are the spot analysed by polarised light. When the brushes have disappeared, a complementary set can easily be brought out by turning the polarised beam through a right angle. We may use the sky as our polariser, and direct the eyes alternately to two portions of it, each ninety degrees from the other, and both ninety degrees from the sun.

The most convenient way for seeing the brushes is to look through a Nicol prism. The brushes will rotate as the prism is rotated, so that when the prism has been turned through 90°, the image is complementary in colour to the image first seen.

185. *Retinal Fluorescence.*—It has been suggested that the extreme violet rays of the spectrum are rendered visible by the retina being fluorescent. (Sect. 67.) According to Helmholtz, both the cornea and the crystalline lens are slightly fluorescent, scientifically a most interesting phenomenon, but one not conducive to clearness of vision.

186. *Want of Achromatism in the eye.*—The eye is approximately, not perfectly achromatic, but for all the ordinary requirements of life this imperfection is of no practical importance. Prof. Stokes gives a simple experi-

ment to show the want of achromatism in the eye. Illuminate a page of small print by throwing on it a pure spectrum, then it will be found that when the print in the yellow light is clear, that in the red and blue it is indistinct, and the paper will have to be moved away from or towards the eye, according as we wish to see clearly the red or the blue part of the page. The want of achromatism is of course most observable for the extreme rays, red and violet, and when white light is looked at, the intermediate and more brilliant colours mask the effect of these extreme rays. But, if a candle is viewed through a glass transmitting only red and violet, we shall see a reddish flame surrounded by a bluish halo, which is the unfocussed image due to the violet rays. The media of the eye are much less dispersive than glass, and this reduces the chromatic aberration.

Although the eye is not achromatic, it is an interesting fact that the hint for the correction of chromatism in optical instruments, by means of a combination of lenses, was taken from the structure of the eye itself. Newton thought that achromatic refraction was impossible. Euler, because he believed the eye to be achromatic, concluded that Newton was wrong. Newton was mistaken, and the basis of Euler's conclusion was incorrect, yet from these two false assumptions resulted (in Dollond's hands) the achromatic telescope. Dollond however saw that the eye, as it did not conform to Euler's rules, could not be achromatic.

An ordinary glass lens is very far from being achromatic. It produces a series of coloured images, corresponding to the waves of different lengths. On account of the irrationality of dispersion no combination of lenses is perfectly achromatic; there are secondary spectra; but well chosen combinations are satisfactory for most optical instruments.

Maxwell, from a series of experiments with the colour-box, comes to the conclusion that variations in colour are more easily detected by the eye than are variations in brightness. (Sect. 148A.)

187. *Colours due to unequal stimulation, etc., of the retina.*—Some curious colour phenomena are produced when a bright surface is viewed through openings cut in a rotating disc. Colour patches and rings, changing as the velocity of rotation changes, are seen. These are due to some abnormal state of the retina caused by alternate exposure to light and darkness. The appearances vanish when the rate of rotation is fairly rapid. With me the colours seen are pale green and purple. The purple flows about like a fluid, and islands of green mottle its surface. (Sect. 152.)

Electrical or mechanical shocks may also give rise to sensations of light and colour. This fact is only an example of the well-known principle—that the kind of sensation, following upon the excitement of any sensitive nerve is always of the same kind as results from stimulating the particular sense-organ with which the nerve is related. The character of the stimulus does not matter. So long as it is the *optic* nerve that is excited, we experience sensations of light. If it is the *auditory* nerve, the sensations are of sound. There is therefore no exclusive relation between light and the sensation of light; the exclusive relation is between the sensation and the optic nerve.

If a bright light be shining on the eyelids the colours of objects are often much modified. Pressure of the finger against the internal corner of the eye causes one to see a coloured spot on the external side. The spot seen may have a steel-blue centre with a brilliant yellow border, and reminds one of a beauty-spot in a peacock's feather.

See Sect. 26 for a possible explanation of the sun looking green through steam.

188. *Hering's Theory of Colour-vision.*—Prof. Hering's ingenious theory of colour-vision should be mentioned. He maintains that the primary visual sensations are white, black, red, yellow, green, and blue, and that these sensations arise as the results of metabolism in the visual substance. Those

changes, which give rise to black green and blue being processes of assimilation, and those, which give rise to white red and yellow, being processes of dissimilation. Black and white, green and red, blue and yellow, are antagonistic rather than complementary pairs, and the retina is conceived of as never existing in a state of complete rest. Hering uses his theory with great ability to explain the phenomena of contrasts and negative images. (Sects. 211 & 220.)

Dr. Pole, who is himself colour-blind, and has paid great attention to the subject of colour-vision, informs me (1887) that Hering's theory suits his own case much better than the theory of Young. See "*Nature*," Vols. 20 & 21.

189. *Development of the Colour-sense.*—Endeavours have been made to show that in past ages the appreciation of colour, as distinct from that of light and shade, was very imperfect. The argument is founded upon the vague use of the words employed to describe colours, and upon the limited number of such words. It is stated that, neither in the Hindoo Vedas, nor in the Parsee Zendavesta, is there an indication of a fully developed colour sense; no mention of blue or green for instance occurring, though the sky and vegetation are often referred to. It is also stated that the sky is not called blue in either the Old Testament or the Koran. Prof. Magnus thinks that mankind at first saw only white black and red, then yellow was perceived in the Homeric period, and later on, blue green and violet.

The colour-vocabulary of English Gipsies is limited to "green," "black," "red," and white." There is no word in Romany for "blue;" and, yet, that Gipsies are not colour-blind, is proved by their appropriating the English word to supply the place of the term missing in their own tongue. (Brit. Assoc. Rept. 1887, pp. 909-10.)

It is very easy to show that the use of colour-terms in modern English is not only loose but even incongruous. The same name is sometimes used for different colours,

and the same colour is often called by different names. The metaphorical senses in which colour-terms are used are very various.

[It seems hardly possible therefore to draw inferences as to the strength of the colour-sense, in either the past or present, from the (supposed) correct or incorrect application of colour-terms.—*Cunningham.*]

Mr. Gladstone has pointed out that very few colours are mentioned by Homer, and, in Mr. Gladstone's opinion, the names are often misapplied. The word "blue" does not appear to be used by Homer as descriptive of the sky. The word (*oinops*) wine-coloured, is frequently used for describing the sea. It appears to mean dark red, and that epithet, it is said, at times aptly describes the Aegean. The epithet, *glaukopis*, applied to Athene in the Odyssey, is by some rendered "gray-eyed;" it, may however mean "fierce-eyed." The adjective *glaukos* means, in regard to colour, pale green or gray (Latin *glaucus*). In botany, glaucous means greenish gray or grayish blue.

For the following interesting and learned note on the Welsh adjective *glâs*, I am greatly indebted to Mr. Powel, Celtic Professor at the South Wales and Monmouthshire University College.

[The word *glas* is used in modern Welsh in three senses, or at least in three sets of relations. It denotes:—

(1). Blue (in its various shades), azure, sky-coloured; e.g., *awyr las*, blue sky; *glas goleu*, light blue; *glas tywyll* or *glas dwfn*, dark, deep blue. A blue eye is *llygad glas;* the blue lias would be described as a *careg las;* slate colour is *glas*, and a certain kind of clay is *clai glas.* The cuckoo is described as an *aderyn* (bird) *glas.* A mixture of milk or butter-milk and water is *glas-dwr* (*dwr*, water), "sky-blue." The word is often used of the sword also, *cleddyf glas.*

(2). Grey, pale, in certain connections; *ceffyl glas*, a grey horse; *gwallt glas*, *barf las*, grey hair, beard; *cangen las*, a greyling (as opposed to *cangen goch*, a chub); *glas-bren*, a sapling (*pren*, a tree), *bore glas*, early morning, &c., &c.

(3). Green, of grass and foliage, as *porfa las*, green pasture, *glas-wellt*, green grass, *caeau gleision*, green fields.

It should be stated that though *glas* is used in the above combinations, yet as a distinctive colour it means "blue" only, "green" being expressed by *gwyrdd*, an early loan-word from Latin *viridis*, while "grey" is represented by *llwyd;* thus for hoary-headed, *penllwyd* is used as well as *penlas*. Intermediate shades are denoted more accurately in Welsh by compound adjectives, as *gwyrdd-las*, greenish-blue, *llwyd-las*, greyish-blue, *du-las*, blackish-blue, &c., &c.; or, on the contrary, *glas-ddu*, bluish-black, *glas-wyn*, bluish-white, &c. In these compounds the second element is always the generic term.

It may be worth mentioning that *glas* is one of the primitive Celtic colour names found in all the dialects. In the three Brythonic tongues, Welsh, Cornish, and Breton, it has the three uses described above. In the three Goidelic languages, Irish, Gaelic, and Manx, *glas* is used only for (2) "grey, pale, wan" (cf. the *bodach glas* of the MacIvors in Scott's Waverley,) and (3) "green." *Glas-fheur* is Irish and Gaelic for grass, just like W. *glas-wellt*. Irish *glas-mhuir* is rendered by O'Reilly "the green sea." When a Welshman uses the cognate form *glas-for*, he probably generally means "blue sea." Gwalchmai, a W. poet of the twelfth century, speaks of *gwyrdd heli*, the green brine. For (1) blue, azure, the Irish and sister dialects have *gorm* (the W. *gwrm*), but this is also used for (3) the "green" of grass. In this way Irish combines (2) and (3) under the term *glas*, and (1) and (3) under the name *gorm*.]

The ability to perceive colours is certainly not at all the same thing as the power of naming them when perceived, so that the argument from poverty of colour names appears to me far from strong. When we examine the brightly coloured works of Ancient Art, when we remember how savages delight in colour, and when we recognise how greatly our present colour language fails in fulness and precision,

there seems no reason to believe in any appreciable development of the colour-sense within historical times.

But there is no doubt that individuals vary greatly in their power of colour-appreciation, and that education can greatly strengthen it. But it is not the physical organ—the eye—which is improved, but the psychical faculties, memory, co-ordination, interpretation, and association, which are developed.

189A. *Colour-teaching for children.*—For teaching Colour to children, wool seems to be the best material, as it can be obtained dyed with very clear and brilliant hues. Black, white, gray, red, orange, yellow, green, blue, violet, purple, and brown, form a good series, and to it may be added some of the lighter and darker varieties, pink, primrose, olive, etc. In the case of children it hardly seems desirable to burden them with uncommon specific names about which opinions may differ. By arranging, in different order, two similar sets of wools we have the means of easily testing the power of a child to match colours. By asking—which two colours make the prettiest pair—the subject of contrasting and complementary colours can be introduced. For sunny days there should be a prism, and pictures of the rainbow and the solar spectrum will be found very useful. Stained glasses or gelatine films are also serviceable.

PART IX.—COLOUR CHANGES DUE TO ALTERATIONS IN LUMINOSITY, AND IN PURITY.

190. *Changes in Luminosity. Increase of brightness.*—In the account of the Constants of Colour (Part III.), it was assumed for simplicity that when the brightness or luminosity of a colour was altered the hue remained unchanged. This assumption however is only partially correct. It is a familiar fact that coloured bodies change their hue under a very bright or a very feeble illumination. Consider first the spectrum. It is found that each of the spectral colours tends to become yellowish-white or white when the intensity of the light is sufficiently increased, as it may be by using direct sunlight. The violet becomes grayish, the blue whitish-blue, the green yellowish-green and at last nearly white, the red tends to orange, the marine becomes undistinguishable from white.

191. *Pigments under a bright light.*—In pigments, with an increased luminosity, obtained by exposing them to a brighter light, we notice the following changes :—red tends to scarlet, scarlet to orange, orange to yellow, yellow looks paler, green is slightly yellowed, marine becomes bluer, dark blue becomes bluer, violet bluer, purple redder, brown becomes orange, olive-green yellow. A piece of ultramarine paper in irregular folds shows in the hollows a blue more violet in tinge than that on the ridges. White paint added to ultramarine does not properly reproduce the brighter tones of blue, for, while increasing the total luminosity, it at

the same time makes the colour paler or less pure, thus really producing tints. The series produce by altering only the luminosity of a colour may be called tones. (Sect. 236.)

192. *Explanation of the foregoing.*—Upon Young's theory the explantion of the foregoing results is easy. For example, the green, so long as its intensity is moderate, acts mainly upon the green nerves; but heighten its intensity, and the action upon the red and violet nerves relatively increases, that upon the red at first predominating, so that the green looks yellowish, but, finally, the triple excitation ends in a colour which is almost white; and so for the other cases mentioned. (Sect. 145.)

193. *Resources of the Artist.*—Artists by taking advantage of these changes are able to represent in their painting the appearance of a highly illuminated scene. If the scarlet of a soldier's coat is painted orange, sunshine is suggested; such is also the case if the green of grass is represented of a yellowish tint. The artist works within very narrow limits in regard to change of intensity, so that he is obliged to resort to certain artifices if he is to represent nature. The sky is not merely blue, it is blue fire; and the painter should be able to dip his brush into liquid light to truly represent it. (Sect. 315, etc.)

194. *Diminution of brightness.*—Again, take a spectrum, and diminish the intensity of the light. One way of doing this is to transmit the light through two Nicol prisms, placed in front of the spectroscope, and then to slowly revolve one of them. The yellow and orange disappear (being encroached on by the red), and the blue is replaced by violet, so that the spectrum, losing its secondary hues, reduces to red green and violet, the fundamental triad. Continue to enfeeble the light, and the violet vanishes, the green becomes very faint, and the red brownish. Then the brown disappears, and a very faint green remains, which, at the final stage, appears as an extremely faint gray.

These changes again favour Young's theory. Orange, for example, is due to strong stimulation of red and moderate stimulation of green, but, as the orange becomes feebler, it fails to act on the green, whilst it still moderately excites the red, so that the orange becomes red.

195. *Colours rotated with black.*—The colour of a disc, painted with any pigment, may easily be darkened by rotating with it another disc stained black (Sect. 70A); or by viewing the coloured surface through two Nicol prisms, one of which is rotated; or by gradually darkening the room. It is rather difficult to see the changes produced by the Nicols, or by darkening the room, for the effect comes on gradually, and the judgment interferes; but the results are like those obtained more easily by rotation.

A red and a black disc give a beautiful series of browns (terra cotta, maroon, coffee, etc.). There is a purplish tinge in the brown obtained with carmine. Orange gives browns, slightly greenish. Chrome-yellow gives olive-greens. A yellowish-green becomes greener, and then dark green. Green becomes dark green. Prussian-blue becomes dark slate-blue. Artificial ultramarine becomes violet. Violet becomes darker. Purple becomes darker and a little less red. Marine darkens, and is said to become greener in character. Blue, violet, and purple, darken rapidly.

The browns and olive-greens, especially the latter, are remarkable, and one might think, in the case of the olive-greens, that some peculiar influence is exerted. But this does not appear really to be the case, for the olive-green, placed in sunlight, appears yellow again.

The general tendency of diminishing the luminosity is that the hues tend to green and blue.

According to Helmholtz the sensation of white is produced when the red green and violet nerves are stimulated to about the *same* degree of activity. With a feeble illumination, he considers that the activity of the violet nerves predominates over that of the green, and that of the green again over that

of the red. With a bright illumination, he holds that these conditions are exactly reversed. This view explains why bright white tends to yellow, and dark white (or gray) to blue. (Sects. 48, 203, & 320.)

Apart from the change of hue, the series produced by mixing a colour with black—that is the series produced by darkening its tone or luminosity—may be called shades. (Sect. 236.)

To show that the black disc does not of itself exert any peculiar action on the colour disc with which it is rotated, we may examine the light reflected from a black disc. It will be found that this light yields to the spectroscope simply a faint continuous spectrum, just like that yielded by a piece of white paper placed in deep shade.

196. Another method of mixing a colour with black is to rotate a coloured sector in front of the opening of a dark room. The coloured light is thus spread over the darkness due to the dark background, and the result to the eye is the same as if the sector had formed the coloured part of an actual circle, of which the rest was black.

197. *Rotation and Palette mixtures with black.*—It might possibly be thought that mixing a pigment with lampblack would produce effects identical with those obtained by combining black with it by rotation, but such is not the case. Carmine and lampblack, mixed by rotation, could not be made to match a palette mixture of the same pigments. The rotation mixture was, even when very dark, much too red in hue. So also the rotation and palette mixtures of lampblack and Prussian-blue cannot be made to match. The palette mixture is much too green. In the case of the carmine, by adding a white disc, a very fair match can be made between a palette mixture of carmine and lampblack, and a rotation mixture of carmine white and black. With gamboge and lampblack, no match can be made between the palette and rotation mixtures, but, on adding a white disc, a fair match results.

198. It is very remarkable that some pigments, when mixed on the palette with black, should give a colour, which can only be matched by rotation by adding a white disc. Purity being defined as freedom from white light, it is evident that the introduction of black in the palette mixture has not increased, but actually diminished the purity of the pigments. At the same time the principal effect of adding black to a pigment is to diminish its luminosity, or lower its tone.

199. *Brilliant and feeble illumination.*—Under a very brilliant illumination, colours become less distinguishable from one another, and degrees of brightness are not well appreciated. Under a very feeble light, colours become also less distinguishable, and small degrees of shade are not well appreciated. The painter to represent a sunlight scene makes bright and less bright objects almost equally bright, while, in a moonlight scene, dark and moderately dark objects are made almost equally dark. (Sect. 319.) A mean degree of illumination is that best suited for discriminating colours. (Sect. 323.) For application to the Colour Cone, see Sects. 247, 248.

200. *Inequality of change in luminosity.*—It is found that red yellow and orange pigments are, in a bright light, relatively more luminous than blue and violet; whilst, in a feeble light, the latter have the advantage. This again will disturb the balance of colour in pictures seen under different conditions. Yellow tints will prevail in sunlight pictures, blue tints in moonlight ones. If a blue and a red paper ot about equal brightness be placed under moderate illumination; then, on diminishing the light, the blue appears the brighter, but on increasing it, the red gains in strength. The eye also is more sensitive to small changes in blue than in red.

201. *Moonlight Effects, etc.*—A landscape viewed by moonlight shows a decided preponderance of faint gray blues and greens. It is estimated that the intensity of

moonlight is more than a million times feebler than that of the noonday sun. Between these extremes come twilights and cloudy days. The effect of a cloudy day can be imitated by looking through a pale blue glass, whilst a yellow glass calls up the idea of sunshine. A picture, painted to be seen by bright daylight, has its colour-balance disturbed as evening draws on. As has been pointed out, colours are more readily distinguishable when they are illuminated to a reasonable extent. Under a very bright or a very feeble illumination they are more apt to be confused. Even under a full moon in England it is not easy to clearly distinguish colours. In the Tropics with a brighter moon the task is less difficult. I have tried to throw coloured patches on the floor by means of stained glasses held in the light of a full moon, but have failed. So that I fear the wonderfully lurid description, given by Scott, is too "highly coloured." The "bloody stain" exists in imagination only.

> "The moon-beam kissed the holy pane,
> And threw on the pavement a bloody stain."

White paper by moonlight is darker than black satin in sunlight, but we never find any difficulty in recognising the former as white, the latter as black. Our judgment at once makes allowance for the difference in the illumination. White paper in shadow may really be of the same gray as a dark surface in sunshine, but we much more easily recognise the fact that white paper in shadow or in sunshine is still white paper. Gray seems to be a different colour, and yet, if we brightly illuminate a gray surface, it looks white.

Tennyson speaks of the "long gray fields" seen beneath the waning light at evening. The description is certainly true for grass and foliage under moonlight. (Sect 327.)

202. *Change in purity.*—We cannot increase the luminosity of a pigment (subjecting it at the same time to no other change), except by exposing it to a brighter light, but it is easy to alter its purity by mingling it with white, either

by rotation, or on the palette, and there will be an increase of total luminosity accompanying the decrease in purity. Combine the pigmented disc with a white disc, and then rotate the two. The general result is easily expressed ; the colour becomes paler, or less rich, and when enough of white is added the hue is lost altogether. Did we not remember how much more luminous is white than any other colour, we should be surprised at the great changes of tint produced by adding it. For example, a disc, three parts white and one part vermilion-red, appears a very pale pink on rotation. But white being four times as bright as vermilion, we are really mixing twelve of white light with one of red.

203. *Change of hue with change of purity.*—Besides producing a paler tint, there is, in the case of some colours, a slight change of hue on rotation with white. Ultramarine blue (artificial) becomes not only paler, but the tint tends slightly to violet. The pale tint, derived from orange, exhibits a slight reddish tendency. Marine tends to become slightly bluer. The alterations of hue (apart from those of tint) are certainly very slight, and I cannot satisfy myself of the correctness of Rood's statement that the pale tints of almost all colours appear as if a little violet had been added to the white we use. (See Helmholtz's hypothesis at the end of Section 195.)

The result of mixing on the palette pigments with white is to dilute them, and produce paler tints, and this is the essential alteration, the increase of luminosity being, as it were, accidental. (Sect. 236.)

204. *Pigments washed over a white ground.*—It might be supposed that the colour, produced by a thin wash of a pigment over white paper, would be the same as that obtained by rotating with a white disc another disc coloured with a deeper wash of the same pigment, but this is not always so. With a deep carmine disc and a white disc, combined by rotation, I could not match a disc coloured by a thin wash of the same carmine. Nor could I produce

a match when with the thinly washed disc was combined a black disc. It was necessary to add a *blue* disc to the combination of deep carmine and white. The following is the equation :

15 cobalt + 53 deep carmine + 32 white.
= 25 pale carmine + 75 black.

This affords an interesting example of how a deep wash of a pigment may essentially differ from a pale wash, not only in purity, but also in hue. (Sects. 21, 36).

205. *Pigments with white and black.*—Pigments may be mixed, either by rotation, or on the palette, with both white and black (that is with gray), producing again a series of interesting results. In the following experiments 100 parts of the disc contained 90 of black, 5 of white, and 5 of some given colour.

Vermilion gave a dark dull slightly purple brown ; orange, a brown ; gamboge, a dark gray olive-green ; emerald-green, a dark slightly gray olive-tinted green ; marine, a very dull grayish dark green ; prussian blue, a very dark gray just tinged with blue ; cobalt, a similar result ; artificial ultramarine, a dark gray tinged with violet ; violet, a dark slaty violet-gray ; purple, a dark gray brownish violet. I do not find it very easy to get out these results clearly.

It will be seen that in mixing on the palette a pigment with *black* the luminosity is always diminished. In mixing a pigment with *white* the luminosity is always increased (for white is more luminous than any other pigment), and, at the same time, the purity is diminished, and this is the essential point. In mixing a pigment with *gray* the purity will be diminished, but the luminosity may be either unaltered, increased, or diminished, according to the relative luminosities of the pigment and the gray. So the effect of mixing white, or gray, with a pigment is not simply opposite to that of mixing black with it ; there is a difference in kind as well. Mixtures with gray may be called shades of tints. (Sect. 236.

For scales of colour see Sects. 236, 237.

PART X. — SUBJECTIVE COLOUR-CHANGES. CONTRAST. COLOURED SHADOWS. PERSISTENCE. IRRADIATION.

206. *Colours changed by change of environment. Simultaneous Contrast.*—The appearance of a coloured surface may be materially modified, without directly meddling with it, by simply altering the colour of the surface adjacent to it. If two small similar bits of red paper are placed, the one on a red, the other on a green, ground, the latter piece appears so much more brilliant and saturated than the former, that we may well doubt if the two pieces are similar. From the artist's point of view the subject of contrast is of great importance.

According to Helmholtz *simultaneous contrast* is independent of the movements of the eyes, and occurs when adjacent coloured surfaces are seen at the same time. *Successive contrast* has to do with the comparison of impressions made on the same part of the retina at two successive times. (Sect. 218.) It is evident, if the eye moves, that we shall get both kinds of contrast, the second succeeding the first. Considering how difficult it is to keep the eye steady, and how small is the portion of the retina which gives distinct vision, I feel very grave doubts as to the separation of these two kinds of contrast in ordinary vision, not directed with scientific precision, but I follow here the usual two-fold division of the subject.

207. *The Laws of Contrast.*—Complementary colours (Part VI.) of full brightness and purity afford the best examples of contrast. For pairs of such colours, see the opposite ends of the diameters of a properly constructed chromatic circle. (Sect. 139, Plate IV.) When a pair of bright complementary colours are viewed in contiguity, the hues are unchanged, but the richness is enhanced. But, if the pair be not truly complementary, or, if the colours differ in brightness or purity, then the difference between the colours, either in hue purity or brightness, will be strengthened by contrast.

This is the primary law of contrast. It may be more simply stated in regard to the three colour-constants.

If two adjacent colours differ in *brightness*, that which is the more luminous will increase, that which is the less luminous will diminish, in brightness. This is contrast in *tone.*

If two adjacent colours differ in *hue*, such difference will be increased, each colour being altered, as if it had been mixed to some extent with the complementary of the other colour. But, if the adjacent colours are themselves truly complementary, no increase of difference in hue is possible, for the difference is already at a maximum.

If two adjacent colours differ in *purity*, the purer of the two will gain, the less pure will diminish, in purity. This is contrast in *tint.*

With regard to this last species of contrast, Mr. J. S. Taylor states that a colour always appears richer in tint by associating it with any other colour, except one more saturated in its own hue. It will then appear poorer in tint.

The whole of the above may be summed up in the statement: that, if two dissimilar colours are placed in contiguity, they are so modified that their dissimilarity is increased.

208. *Contrast and Luminosity. Tone-contrasts.*—We may now consider those effects of contrast, which are connected with differences in brightness, and are usually called

tone-contrasts. (For the general law see Sect. 207.) First, consider grays. If pale and dark gray are placed together, the pale looks paler, the dark darker. But the effect is still more striking when several strips of gray, varying in tone, are arranged in series. When this is the case, all strips, except the end ones, are subjected to double contrast, the third strip, for example, looking paler on the edge adjoining the darker fourth strip, and darker on the edge adjoining the paler second strip. The series of strips presents to the eye the appearance of a surface hollowed by a number of parallel flutings.

If, on a white disc, we paint a series of black sectors (Plate III., Fig 3), decreasing in angular magnitude towards the circumference, and then rotate the disc, we see a series of gray rings, each being lighter than the one it encloses, and darker than the one by which it is enclosed. Sect. 100B.) Each ring is really uniform in tint, but will not appear so. The rings appear shaded, each having a bright inner rim where it adjoins a darker ring, and a dark outer rim where it adjoins a lighter ring. Similar effects can be produced with tones of colours other than gray. The contrasting tones should differ considerably, should increase by regular steps, and should be in contact, if the results are to come out well. Dull red upon bright red appears dingy; bright red upon dark red appears brighter than before. A brilliant hue has an injurious effect upon dull shades of the same colour. Sometimes a hue, complementary to the bright colour, is evoked upon the dark one. (Sect. 211.)

A beautiful natural example of the appearances produced by a series of adjacent tones of gray is afforded us by a landscape containing mountain ranges rising one behind another. The lower portion of any selected range will appear brighter than its upper portion, for this lower portion will be adjacent to the darker upper portion of the range in front of it, whilst the upper portion of the selected range

will be adjacent to the brighter lower portion of the range behind it, The sky-line will darken by contrast the upper portion of the furthermost range.

209. *Importance of Tone-contrasts.*—For the painter nothing is of more importance than truth of tone. Tone-contrasts are constantly used in light and shade drawings, in pictures in monochrome, and, of course, in ordinary paintings.

Slight touches of white will apparently darken spaces that were too pale, and spaces too dark may be brightened by a few touches of black. The contrast of white and black is the strongest known. It is stated that we can tolerate a shortcoming in colour-contrast better than one in light and shade. For the recognition of objects light and shade are fundamental, but colour is subordinate. (Sect. 329.)

210. *Colours contrasted with White Gray and Black.*—Next may be considered the effect of contrasting colours with white gray or black. All colours seem brighter in *tone* on a black ground, and darker in tone on a white ground. The effect produced by a gray ground will depend upon the particular tone of the gray and of the colour placed upon it. With an "equivalent" gray (Sect. 72) there will be no change of tone in the positive colour, but a darker gray will brighten the tone, and a lighter gray will darken it.

The apparent increase or decrease in luminosity, which is the important factor in the contrasts just named, gives rise to slight changes of *hue*. Red placed on a black ground is brightened, and appears tinged with orange, as we are accustomed to see luminous red tend to orange. (Sect. 191.) Dull red looks brownish on a white ground. Very pale red, on a black ground, looks white.

With regard to contrast and *tint*, colours look richer upon a black gray on white ground than they do upon one of their own colour, that is to say, their puiity is apparently increased. (See also Sect. 280.)

211. *Complementary colours evoked by contrast.*—Besides the change of tone and tint, there will be a change of *hue*, both in the neutral ground and in the positive colour. The neutral ground will be more or less tinged with the complementary of the colour placed upon it.

To evoke these subjective complementary tints it is better to use *gray* than white or black, for the exciting colour is less luminous than white, but more luminous than black, and it is important to use a ground, whose brightness is properly adjusted to that of the exciting colour. Artists are familiar with what is termed an "adjacent gray." So also, if the ground be coloured, and we place upon it strips of paper in order to see the effect of contrast, it is better to use gray strips than either white or black.

Very marked examples of the effect of simultaneous contrast are produced by placing narrow strips of gray upon various coloured grounds. It will be found that the gray strips are tinged, to a greater or less degree, with colours complementary to those of the grounds on which they rest. A gray pattern, traced upon a green ground, appears of a beautiful rosy tint complementary to the green, and so for other colours. (See complementary colours, Sect. 139.) To well bring out the complementary effects, the gray strip should be of suitable tone and should be quite surrounded by the coloured ground. Green is more powerful than any other colour in evoking subjective colours. (Sect. 286.) Patterns worked in black upon brightly coloured grounds will be found to exhibit feeble complementary tints.

To get the effect of pure gray upon a green ground, the gray must be made somewhat greenish, so as to counteract the complementary effect. The same is true for other coloured grounds. This fact is of importance to the artist. (Sect. 321.) Upon a bright green ground a gray strip looks pink, a pale green one gray.

If a small gray spot, placed on a green coloured background, be put under a sheet of thin white tissue paper (covering both), then the complementary tint seen on the

gray is much intensified, but it is not easy to say why. Is there an illusion of the judgment, the pale green tissue paper being taken as a standard white? (See also Sects. 226-7.)

If a field of snow be looked at through a green veil, although the light which reaches the eyes must have a greenish tint, it looks reddish, from the effect of the after-image of the green. This illustrates the fact that we are able to separate the colour which belongs to a transparent medium from that of the coloured objects seen through it. (Sect. 182.)

212. *Gorham's Circles.*—Mr. Gorham has produced a very simple and ingenious arrangement for seeing complementaries upon gray. A circle of brightly coloured paper has an annulus cut out of it, and the annular space is then filled again by an annulus composed of a few thicknesses of white paper, sufficient to reduce white light to gray, if passed through it. If such a disc be properly illuminated, the annulus (which transmits just enough light to be gray) will appear vividly tinged with a colour complementary to the colour of the circle itself. The best effects are brought out by carefully adjusting two lights, one behind, the other in front of, the paper disc, until the coloured disc and its annulus are properly "toned" to give the maximum result.

213. *Examples from Nature of Complementary Contrast.*—In the Romsdal (Norway) is the well-known Slettafos, an imposing cascade, plunging through a deep rocky ravine. Whilst watching (1882) the foaming water, I noticed a beautiful delicate rosy-pink tint colouring the foam and spray in the ravine. The water, where not broken up, was of a green colour, and the pink was at once explained as its complementary. But the point of special interest was that this pink tint was only visible on those parts of the spray and foam, which were in the *shade* of the gorge. In the full light, the foam was white. This is an excellent illustration, afforded us by Nature herself, of the advantage of toning down the bright white adjacent surface, until its luminosity

was suitable for the green to evoke upon it the complementary rose-pink. At the falls of Schaffhausen, in 1797, Goethe noticed that, when the running water appeared green, then the adjacent foam took on a light purple tint. The foam of Niagara, of the Rhone, and of some other rivers, presents similar phenomena.

Wavelets in rich brown-coloured water often display an amethystine tint in their shadowed portions, and the foam-crests of sea-waves, curling over, may appear of a delicate pink tinge.

The shadows of cloudlets at sea are frequently tinged with a colour complementary to that of the water—purple—if this is green. In the beautiful emerald pools, in the Geyser region of the Yellowstone Nat. Park, the shadows are of sombre purple.

Though an objectively green cloud is never seen, yet green or bluish-green as a subjective complementary, is often visible in those parts of the sky adjacent to the brilliant red clouds of sunset. The effect is specially good when there is a large bright red cloud with small openings through which the sky behind may appear. In a reddened sky the moon looks decidedly green. (Sect. 57.)

"The moon was falling greenish through a rosy glow."

214. *Contrast and Hue.*—Consider now the case of the association of two different colours, that is to say the effect of contrast for difference of *hue.* (General law, Sect. 207.) Place a small square of ultramarine paper upon a bluish-green ground, the ultramarine will incline to violet. Place a small square of bluish-green paper upon an ultramarine ground, and the square will look greener than before. Each square acquires something of the colour complementary to that of the ground upon which it is placed. The ground colour is also affected in a converse way, but the change in it is usually only apparent in the area immediately adjoining the small square.

Another way of performing this experiment is to place the two small squares in contact upon a gray ground, and to place two similar squares upon the same ground, at some distance from the two first squares and from each other. We can then compare the change of hue, produced by contrast in the two adjacent squares, with the same hues unaltered in the distant squares. (The gray ground will cause slight alterations in tone.) If red and yellow are placed together, the former becomes purplish, the latter greenish. With red and marine there is no change of hue, but both are brighter. With green and blue, the former becomes yellowish, the latter purplish. With violet and greenish-yellow, there is no change save in brightness. All these changes illustrate the law given in Section 207.

A few more examples may be given. Red and blue become by proximity respectively more orange and more green. Red and violet, more orange and more blue. Yellow and blue, both more brilliant. Yellow and green, more orange and more blue. Green and violet, yellower and purplish. The alterations in hue and brightness are greatest in those parts of the coloured squares which are immediately adjacent.

Chevreul deals largely with contrast, but his work requires treating with much caution, being based upon an erroneous theory of colour, whilst there is a want of exactitude in the methods employed. In studying contrast effects Chevreul went entirely by the judgment of the eye. But there are many objections to this, as the eye is very liable to be influenced by association, etc.

The rotation method with discs can be used with advantage. Suppose we want to see how green is altered by contrast, say, with blue. We take two similar small green discs, and place one of them on a large surface of blue, the other on a neutral ground. The two discs no longer appear alike. We can then combine with the second disc another disc (in this case it must be a yellow one) and adjust the proportions until the rotating compound disc

exactly matches the first simple disc on the blue ground. The proportion of the yellow to the green in the second disc will give us an estimate of the amount of alteration in the first disc due to contrast. The results obtained confirm the theory that regards red green and blue as the primaries, and are opposed to the red-yellow-blue theory. (Sect. 223.)

214A. *Exact experiments in contrast of hues.*—In order to entirely eliminate the effect of the background in contrast experiments, it has been suggested (by Mr. J. S. Taylor) that each colour should be placed upon a ground of its *own* colour, being separated from it by a thin line only.

Consider first two different colours of *similar* hue, say, light and dark blue. Take two small light blue circles, a, b, and two large ones, A, B. Take also two small dark blue circles, c, d, and two large ones, C, D. (Plate VI. 2.) Place a on A, b on C, c on B, and d on D. Then b will be lighter than a, and c darker than d, in *tone;* also, b will be paler than a, and c richer than d, in *tint.*

Secondly; consider colours widely *different* in hue. Let A, a, b, B, be red, and C, c, D, d, be blue, placed as before, then b, c, will appear richer than a, d, in *tint;* and also b will look more orange than a, and c more green than d, in *hue*, owing to the complementary law.

Thirdly; take colours *closely allied* in hue, A, a, b, B, being red, C, c, D, d, orange. Then (placed as before) b, c, will appear slightly richer than a, d, in *tint;* and b will be rather purple, and c rather yellow, in *hue.*

Lastly; take *complementary* colours, A, a, b, C, being red, and B, c, D, d, marine; then b, c, will both appear richer than a, d, in *tint*, being enhanced in purity as much as possible, but not altered in hue.

In these three last cases there are also slight modifications in tone, but these are not of much importance.

215. *The Chromatic Circle and complementaries.*—With the aid of the Chromatic Circle (Sect. 139) it is easy to study the changes produced by contrast. As Prof. Rood

points out, if we wish to study the effect of any colour, say, *red*, on all the other colours of the circle, and also on itself, we may superpose two chromatic circles, so that the colours of the one rest on the similar colours of the others. We then slide the upper circle for a little distance, by moving its centre directly towards the marine-coloured end of the red-marine diameter of the lower circle. We then note the new positions which the colours of the upper circle occupy compared with those in the unshifted lower circle. Marine will be further from the centre, but in the direction of the same diameter as before; it is therefore made richer in tint by the red (which is in fact its complementary), but is not changed in hue. The red will be found on the same diameter, but nearer the centre; it is therefore made duller in tint by the red (its own colour), but is not altered in hue.

Orange will be found moved nearer to yellow, so that red causes orange to appear more yellow in hue. The orange being also rather nearer the centre of the circle, Prof. Rood states that it will appear slightly poorer in tint, and this may be so; but, compared with orange seen against a background of its *own* colour, the orange, we are considering, is slightly richer.

It appears that when the chromatic interval is small (e.g., red and yellow), the contrast-change of hue is great, whilst that of tint is small; but that when the interval is large (e.g. red and blue), the change of hue is small, but is accompanied by considerable change of tint; and, lastly, if the interval is the greatest possible (e.g. complementaries, red and marine), the change of hue is nil, but the change of tint, in the direction of increased saturation or richness, is at a maximum.

When the chromatic interval is zero, that is when the contrasting colours are identical, they will appear the same in hue, but duller in tint. If a number of similarly coloured pieces of paper are examined in succession, the last will appear the dullest.

It may be interesting to recall the fact, mentioned in Section 140, that a comparatively small change of hue in the blue to green colours, is accompanied by a comparatively large change in the colours complementary to them. This may be one reason why blues and greens are difficult to manage in a painting, but the usual reason assigned is the "coldness" of these colours. (Sects. 272, 284, 289.)

216. *Helpful and harmful Contrast.*—Contrast is helpful or harmful to colours according as it makes them more or less brilliant and saturated. It is easy to arrange bright colours so that they damage each other; whilst a good painter can dispose even mild tints so that they enhance each other. Physiologically speaking, the best contrasts are those of the pure complementaries; but there is an aesthetic side of the subject, and we shall find that the use of pale tints often affords great pleasure by suggesting the presence of atmosphere light and distance. Light and shade have a powerful effect in tempering colour-contrasts which might in themselves be undesirable. Mild contrasts also are greatly enjoyed after brilliant ones.

The following is a simple example of harmful and of helpful contrast. A strip of pale marine colour, placed upon a bright green ground, looks gray, and may serve to illustrate a harmful contrast; but, placed on a carmine-red ground, its colour is enhanced, and we see a good contrast effect. (See also Part XIII.)

217. *Contrast and Purity.*—Some additional remarks on contrast in relation to the purity of colour may now be made. For the general law, see Sect. 207.

A pale red slip of paper placed upon a rich red ground looks paler than before. A still paler slip may look white, whilst, if still more feebly tinted, the effect of the rich ground colour may be such as to cause the slip to appear greenish-blue, the colour complementary to that of the ground. (Sect. 211.)

Whilst the pale tint appears paler, the deep one will appear deeper, but to see this well it is best to place a small deep strip upon a large pale ground, See also Sect. 214A for other precautions. If two pieces, one deep and the other pale, both of equal area, are placed in contact, both are altered as above described, the alteration being at a maximum along the line of junction, and diminishing as we recede from this line.

Of course the contrast effects, due to tone tint and hue, may all be present simultaneously. Take a dark rich blue and a bright pale red. When juxtaposed, the blue will look darker richer and greener, the red brighter paler and yellower, the threefold change being due to increase of contrast in tone tint and hue respectively. If the colours had been equally bright, there would have been no change of tone; if equally impure, no change of tint; if complementary, no change of hue. If the colours were similar in hue, but not in tone or tint, there would be no change of hue, except in so far as change of tone or tint gives rise to change of hue.

218. *Successive Contrast.*—This kind of contrast (Sect. 206) is associated with movements of the eye, especially when the glance passes over surfaces which largely differ in brightness or colour. As the eye passes from one colour to another, the second colour falls on a retina, which has just been exposed to the first colour, and is therefore altered in sensitiveness.

The exhaustion of the retina by brightness, or by colour, need not necessarily extend over the whole of it. If the object, first seen, fills only a small definite area of the field of vision, then that part only of the retina will be altered in its sensitiveness to the image of the second object. Look for sometime at a brightly coloured surface, and then look at a gray ground; this ground will appear tinted with a colour complementary to the colour first looked at. If the first colour be red, the gray will appear of a marine tint.

219. *Explanation.*—Upon Young's theory the explanation is as follows: the red nerves by continued gazing on red are fatigued to a degree much greater than are those which respond to blue and green, so that, when the gray surface is looked at, its red element is weakened, and it appears of a colour—gray minus red, that is of a marine tint complementary to red.

In the experiment just described the eye looked first at a red surface, and then moved to look at a separate gray one. A simpler way of performing the experiment is to place a small red patch upon a gray ground, and then, after looking steadily at the patch, to suddenly remove it, without shifting the eyes. We shall then see, on the gray ground, a complementary marine-coloured image similar in position and area to the original red patch.

Tested in the same way, patches coloured yellow, greenish-yellow, green, marine, blue, violet, and purple, give images, coloured respectively, blue, violet, purple, red, yellow, greenish-yellow, and green. A white and a black patch placed on a medium gray ground, and steadily looked at, leave behind them, when removed, two gray images, the first darker, the second lighter, than the ground. A stained glass window gives a beautiful complementary after-image.

220. *Negative Images.*—Images produced in this way are called *negative* images, because they are in exact contrast to their exciting colour.

The experiments may be interestingly varied by placing the coloured patches upon, not a gray ground, but one of some positive colour. The negative image of a green patch, placed on a yellow ground, is not purple, as it was with gray, but orange. The explanation is as follows. When the green patch has been removed, the space which it covered sends yellow light to the eye. But this yellow light excites both the green and the red nerves. Now the green nerves have been fatigued, so that we get a strong red

mingled with a weak green sensation, that is a sensation of orange. In this experiment the violet nerves do not come into play to any important extent.

By similar reasoning, if a green patch be placed on a blue ground, the image, after removal, will be violet, owing to the weakening of the green sensation in the blue, which excites both the green and violet nerves. In this experiment the red nerves scarcely come into play at all.

The general result is that the after-image has a colour similar to that of a mixture of the original ground colour with a colour complementary to that of the patch ; or perhaps it is better stated that the after-image has a colour which is that of the ground upon which it is seen minus the colour of the original patch.

221. *Intensifying a Colour by contrast.*—Place a black square upon a red ground, and after viewing it for some time, suddenly remove it, and an intense red image of the square will be seen upon a dull red ground ; because the part of the retina upon which the image of the black square fell has been kept fresh, while the surrounding parts have had their red sensation fatigued. A still more pure and intense red image is seen, if, instead of a black square, we use a marine one, complementary to the red ; for then we shall not only have kept the red nerves fresh, but shall have fatigued the green and violet ones.

Write a page or two in red ink, and then on using black ink the writing will appear of a blue-green tint complementary to the red.

By using both eyes and fatiguing one, but not the other, it is easy to see the same surface of two different colours, according to the eye with which we view it. (Sect. 145.)

222. *Subjective Colours.*—Colours produced by modifications in the condition of the eye may be conveniently called *subjective* colours.

223. *Complementary Contrast and the Theory of Colour.*—The complementaries evoked by contrast strengthen Young's theory, but weaken Brewster's, for we find that the complementaries to red, green, blue, and yellow, respectively, are marine, purple, yellow, and blue; and not green, red, orange, and purple, as Brewster's view would make them to be. We have only to actually place together the colours (which are complementary by the one or the other theory), to see how much better are the contrasts furnished by Young's theory. (Sects. 160, 214.)

224. *Coloured Shadows.*—Place a rod so that a lighted candle may throw a shadow of it on to a white screen. Allow diffused daylight also to fall upon the screen. The shadow will appear decidedly *blue.* It will be obvious that the shadow itself is entirely free from the light of the candle, but that it is illuminated by a white light of low intensity; it may therefore be considered as gray. This gray is seen upon a ground lighted mainly by the yellowish illumination of the candle. The complementary blue colour of the shadow is therefore easily explained as due to simultaneous contrast.

On a screen lighted by a green light the shadows are of a beautiful purple colour. In a church with windows of greenish glass this effect is easily seen. With a red glass the shadows are green-blue or marine.

When sunlight falls upon a window screened by an orange blind, the general body of light is of course orange coloured; but where any rays pass by the edges of, or through holes in, the blind, they will appear of a bright complementary greenish blue. (Sect. 321.) The bluish shadows of trees at sunset time are mainly due to complementary contrast with the yellow and orange ground upon which they fall. If the sunset is red, the shadows should show a marine colour. But it will be understood that, as the shadows are lighted to some extent by all the parts of the sky which do *not* cast them, there is room for considerable variety in their hues. (Sect. 57.)

If a shadow upon a coloured ground is absolutely black, receiving no side illumination at all, it would not, I think, be able to display any complementary colour. But it hardly ever happens—unless matters are artificially arranged—that a shadow is absolutely lightless.

225. *Shadows with two Coloured Lights.*—With two shadows, thrown on the same screen by two differently coloured lights, the colours are very beautiful. In this case we have a screen lighted by a mixture of the two lights, and we have two shadows on this coloured ground, each shadow being illuminated by that light which casts the other shadow.

If the two lights are red and green, the yellow ground they produce will tend to give by contrast a blue tinge to both shadows ; so that the shadow lighted by red will tend towards purple-red, and the other lighted by green will tend to bluish-green. The effects are enhanced if the shadows are adjacent. Two lanterns may be used to furnish the coloured lights. It will be found also that two induction sparks, taken between pairs of different metals, will cast very beautiful coloured shadows. With a yellow light and a white light (a candle-flame and daylight) the shadow cast by the yellow light is blue, that by the daylight, yellow. (Sect. 117.)

226. *Cause of the contrast-effects of brilliant Colours.*—The phenomena of contrast exhibited by brilliant colours, whether the contrast be successive or simultaneous, appear to be due mainly to retinal exhaustion. In the case of two adjacent colours, the first colour renders the eye less sensitive to those constituents of the second, which the first may happen to possess, while the eye becomes more sensitive to those constituents which are absent from the first. Similar reasoning applies to the second colour. But it is difficult to attribute the tissue paper experiment (Sect. 211) to retinal exhaustion. See also Sect. 227.

227. *Simultaneous Contrast, and illusions of the judgment.*—Prof. Rood states that many of the effects produced in simultaneous contrast are due, not to retinal exhaustion, as is the case in successive contrast, but to an illusion of the judgment. In ourselves we carry no *fixed* standard by which we can measure the purity of a colour or its exact place in the chromatic scale. So, if we have no clear external standard at hand for puposes of comparison, we may easily be deceived. It is not easy to say in every case of contrast how much is due to retinal exhaustion, and how much to illusion of the judgment.

The following experiment strikingly illustrates the influence of illusion. A blue shadow is produced as described in Sect. 224. The shadow is then looked at through a small tube, so held as to include in the field of view some of the yellow ground and some of the shadow. The tube is then gradually moved until the shadow fills the entire field; it still looks blue, though the contrast action of the yellow ground has been removed; and it continues to look blue, even when the candle is blown out; but the illusion instantly vanishes if we remove the tube. The shadow, as we know, was never really anything but gray, but, being seen as blue, the judgment persisted in so regarding it, until the tube was removed. But if we include in the field both the yellow ground and the blue shadow, then, on cutting off the candle light, the whole field becomes gray or white.

228. *Persistence of Retinal Impressions. Positive After-Images.*—Close the eyes for a short time, then look at a bright window for a moment or two, and close the eyes again. An image of the window, *corresponding* to the natural one, the sashes dark, the panes bright, will be seen, and will last for a little time. Look in the same way, for a moment only, at a coloured light, and then at a gray surface, an image of the *same* colour as the light will be seen. These results show that the sensation is of longer duration than the application of the stimulus. Images such as these are called *positive after-images*.

The duration of the impression on the retina appears to vary in the case of different colours. Prof. Stokes states that, when watching the fiery balls discharged from a Roman Candle near at hand, he saw moving stars of red, but described curves of blue, indicating that blue persisted longer than red. If a blue patch be painted upon a red surface, and the surface be suddenly moved, the blue patch will appear to move relatively to the surface, owing to the difference in degree of retinal persistence of the two colours.

When excited by a very bright light, such as the sun or burning magnesium, the positive after-image often endures for a long time, and generally changes colour as it fades away, the colour-changes varying with circumstances. But with a bright light the effect is not a simple one. We shall have a positive image gradually dying away and blending with a negative image due to retinal fatigue; and the fact that the duration of after-images varies with the different colours composing white light, will cause changes of colour, and give rise to complicated phenomena. (Sect. 232.) When lights of different intensity, but of the same colour, are whirled rapidly round it is found that the brighter the light the more rapidly must it rotate to give the impression of a uniform ring of light.

229. *Mixture by rotation is due to persistence.* If a string lighted at the end be rapidly whirled, the revolving light, owing to retinal persistence, is seen as a circle of fire, provided that it completes about eight revolutions per second; but the minimum rate varies slightly with different colours. The blending of colours by the rotation of the sectors upon which they are painted (Sect. 78) depends upon retinal persistence. If a rapidly rotating disc is lighted up by an electric spark, it appears to be absolutely at rest with all its colours distinct,

A white spot, painted on a black disc, looks like a gray annulus, on rotation of the disc. The white is, as it were, spread over the whole ring, and its luminosity is consequently

enfeebled. By comparing the angular magnitude of the spot (which should have the shape of the sector of an annulus) with that of the entire annulus, of which it is a sector, we get a quantitative estimate of the amount of dilution.

230. *Proof of the method of rotation.*—That the rotation method is correct is easily proved. A disc, half white and half black, is set in rotation, and the gray produced is compared with either of the images seen on viewing a strip of the same white paper through a double image prism. It will be found that either of these images is a gray of the same luminosity as that of the revolving disc; and we know that either of the prism images has just half the luminosity of the white paper. (Sect. 74.) The above investigation holds good also for coloured surfaces. These facts are of great importance, as upon them is based the correctness of the inferences drawn from the experiments with Maxwell's discs.

231. *Persistence and the perception of moving objects.*—Our perception of the rapid movements of waves and waterfalls, of the limbs of swiftly running animals, of fluttering leaves, etc., is largely modified by the positive after-images due to retinal persistence. Seen by a flash of lightning, by an electric spark, or in an instantaneous photograph, these objects appear as if at rest in the one position they happen to be in at the moment. The instantaneous picture, though scientifically accurate, may be artistically displeasing, for the generalised effect given by the artist corresponds to the blended images seen, and is therefore to us more really truthful. (Sect. 327.) The zoetrope, and similar instruments, produce their effects by the aid of retinal persistence.

232. *Further remarks on After-images.*—It will be understood that ordinary cases of retinal persistence are due to positive after-images, which are simply continuations of the sensations which preceded them. They are best seen after a momentary exposure of the eye to the stimulus.

The negative after-images occur after the withdrawal of a stimulus to which the eye has for some time been exposed.

The subject of after-images is somewhat complicated and is not yet fully understood. If a brightly lighted window be looked at for some time, and the eyes are then closed, probably the positive image will not be seen. If it is, it will shortly be succeeded by the negative one, and this image will often be seen to go through several changes of colour. On looking at a white spot (lighted by sunlight) on a dark ground, I see a dim bluish halo bordering it. On closing the eyes, I see a green image lasting for some time, and changing to red, and then to black. (Sect. 228.)

Hering bases his colour theory (Sect. 188) largely on the phenomena of contrast and after-images.

233. *Irradiation.*—If two patches, one black the other white, both exactly of the same size, be placed, the former on a white ground, the latter on a black ground, the white patch will look *larger* than the black one. So too, a highly heated fine wire seems enormously thicker than it really is. The crescent moon appears to belong to a disc much larger than the dimmer disc of which it really forms a part. Round the edge of a small coloured circle may often be seen a narrow rim of light tinted with a colour complementary to that of the circle. This effect may be due to irradiation, or, possibly, to slight involuntary movements of the eye (successive contrast).

The peculiar star-like figures, with six rays, seen as if radiating from a bright luminous point, are due to the hexaxial structure of the crystalline lens. That such rays do not exist apart from the eye is easily proved by turning the head on one side, when the rays will be seen to turn with the head. The small bright crescent moon appears to me tripled, owing to the same pecularity of the lens.

To represent a bright star the painter should show it with six diverging rays. (Sect. 321.)

Much of the peculiar mystery and indefiniteness, which enhance the beauty of flames, sun-lighted water and metals, etc., is due to irradiation.

234.—*Causes of Irradiation.*—Two causes have been assigned for irradiation ; the first cause attributes it to imperfect transparency of the humours of the eye, combined with spherical aberration ; the second explains it by the supposition that the area of the retina, excited by a bright object, is larger than that of its retinal image, there being a diffusive action. Both causes are probably at work.

The eye suffers, not only from spherical aberration, but also from astigmatism, but these defects are connected only remotely with colour phenomena.

235. *Partial and general retinal exhaustion.*—It has been seen that the effects of successive contrast, and many of those of simultaneous contrast, are due to partial retinal exhaustion, which prevents full appreciation of the three primary elements of colour. An excessive white light will produce *general* exhaustion, rendering the retina less sensible to *all* colours, and therefore not developing subjective colour phenomena. By repose, and in darkness, the retina regains its freshness. (Sect. 317.)

Briefly to sum up, it may be said that the phenomena of Contrast, After-images, Persistence, and Irradiation, are due, not to physical, but to physiological causes.

PART XI.—SYSTEMATIC CLASSIFICATION OF COLOURS.

236. *Colours positive and negative. Tones, Shades, Tints, Shades of Tints. Scales.*—Colours are sometimes divided into *positive* and *negative*, the former including all "chromatic colours" together with white and gray, the latter including only black. I prefer to exclude gray and white from the positive colours, and to class them with black as negative colours. Sometimes white gray and black are called "achromatic colours." Some authors distinguish between "grey" and "gray;" the former denoting only a mixture of white and black; the latter denoting any chromatic colour largely diluted with "grey," so that the word "grays" would signify those colours, which form the broken tints of the dulled scale, to be presently referred to. I have not observed this distinction, but have used "gray" for the mixture of black and white.

In what follows we neglect the slight alterations of *hue* produced in mixing a colour with white gray or black. (Sects. 195, 203, 205.) The *tone* of a colour is estimated by the amount of colour-sensation it excites, and depends on the luminosity. (Sect. 69.) Darkened tones are called *shades*, and are made by mixing a colour with black. The series produced by mingling a colour with white may be called *tints*. (Sect. 69.) If we mingle a colour with both white and black, that is with gray, we really get shades of tints. (Sect. 205.) The above explanations apply both to pigments and coloured lights.

Each colour admits of three scales :—

(1) The *darkened scale*, that is the series formed by mixing the normal hue with progressive increments of black, thus reducing its tone or luminosity, and forming *shades*.

(2) The *reduced scale*, that is the series of impure colours formed by mixing the normal hue with progressive increments of white, thus reducing its purity, and forming *tints*. (Tints are more luminous than the colours from which they are derived, because white is more luminous than any positive colour.)

(3) The *dulled scale*, that is the series formed by mixing the normal hue with progressive increments of gray. As gray is a mixture of white and black, we can regard the white and the normal hue as forming a tint, which will then be reduced by the black, the joint action thus producing *shades of tints*, sometimes called "broken tints" or "grays." These broken colours might also be called "tints of shades." (Sects. 132, 266, 285.)

237. *Production of the Series in a Scale.*—The series in each of these scales may be produced in two ways: First, by mixing together by weight in different proportions the given pigment with a white black or gray pigment: Secondly, by painting a disc with the pigment, and blending its colour by rotation with the white black or gray of another disc, the discs being slit along a radius, so as to allow of our using sectors of any angular magnitude we please. Or, we may use a compound sector, or a heart-shaped piece, superposed upon a disc.

See also Sects. 100B, 208, Part IX., and Plate III. It will be remembered that palette mixtures of a colour with black white or gray are not necessarily identical with the corresponding rotation mixtures.

238. *Difficulty of Colour-classification. A complete scheme.*—The classification of colours is a difficult and complex problem. A complete scheme should include black, white, gray, the spectral colours, and purple, and the series in the scales produced by mixing these colours with white black or gray. As was stated in Sect. 71, the eye can distinguish an enormous variety of colours.

Colour names are far from being definite or numerous enough. The names purple and violet, the former containing red, the latter not, are often applied indiscriminately. Some interesting points appear when we consider language and colours. (Sect. 189.) Red and orange, when darkened, appear so different that a new word *brown* is used for the result, but, for dark green or dark blue, there is no special word. Again, the colours between blue and green are difficult to discriminate, and are called blue-greens, or sea-greens, or green-blues. Feeling the want of a convenient word for the colour exactly between green and blue I have used the word *marine*. The fact that we never speak of a greenish red or a reddish green would almost lead us, *a priori*, to infer that such colours do not exist, and we know, from the law of colour mixture, that red and green when united produce a new colour, with a name of its own—yellow. Also we never speak of a yellowish blue or a bluish yellow; for such colours do not exist. Yellow and blue produce white, and, if there be an excess of either, we get simply a yellowish white or a bluish white. Similar remarks apply to every complementary pair. To me, orange does seem to suggest red and yellow, and the colours between yellow and green suggest their possible components. Green does not suggest anything but itself. The colours between green and blue suggest their possible components, so do those between blue and violet. Purple also suggests red and blue. I cannot say that yellow suggests red and green. (Sect. 123.)

239. *Chevreul's Circles.*—Chevreul's graduated series of chromatic circles, containing typical colours and their mixtures with white and black, is far from satisfactory in execution, and is based upon the erroneous theory that red yellow and blue are the primaries.

Chevreul employed a circle with three radii, 120° apart, and upon these radii were placed red yellow and blue respectively. Between red and yellow were placed the

various hues of orange, etc.; between yellow and blue the greens; between blue and red the purples. The first circle contained the purest colours. In the second the same colours are shown mixed with a small definite amount of black. The third contained more black, and so on. Another series showed the effect of mixing colours with progressive amounts of white.

240. *Werner's System for Minerals.*—In 1774 Werner made a classification of colours for the purpose of describing minerals. (Sect. 313A.) The system will not stand critical examination, but, some of the names, being derived from well-known substances (mineral animal or vegetable), may be adopted with advantage. Substances which can be easily obtained in the same physical condition are very convenient as standards of reference; e.g., sulphur, gold, vermilion, lapis-lazuli, cochineal, saffron, etc.

241. *The spectrum the standard.*—But the solar spectrum, with its fixed black lines, is the best theoretical standard of reference. (Sects. 9, 10, 11.) For a truly philosophical and complete classification of colour neither our experimental means nor our knowledge is at present sufficient, and the practical production of perfectly similar colour-charts, based upon a truly scientific foundation, seems almost unattainable.

242. *Circular arrangement of Colours. Newton.*—With the colours of the spectrum, and purple, we can match any colour, if we increase or diminish the luminosity of the hues, and add the necessary amount of white light. This fact suggests a method of classifying colours. The series, red to purple, is one which returns on itself, and hence can be put in circular form, as was first done by Newton. (Sect. 101.) A small chromatic circle will contain only a few colours, say the primaries and secondaries, so placed round the circumference of a circle, that any two colours, complementary to one another, will be at opposite ends of the same diameter.

The number of separate hues represented is a matter of practical convenience, and, in the chromatic circle, described in Section 139, there are twenty.

243. *Circular Chart.*—To make the circle into a colour chart, we place a ring of colours, as pure as possible, round the circumference. White will be in the middle of the circle, and surrounding this will be a series of rings containing tints of the colours on the circumference, the tints being more and more mixed with white, as the ring upon which they lie is taken nearer and nearer the centre. We shall thus have a series of sectors, bounded by a ring of pure colours at the circumference, but becoming whiter as we approach the angular points of the sectors at the centre of the circle. The red sector will be pure red at its circumference, and then paler and paler red, until it is white at its origin; and so for other colours.

Such a circle will contain every possible hue and tint to be found under a given degree of illumination.

244. *Intensity of Complementaries.*—The complementary colours are to be opposite one another, and, according to Prof. Rood, the luminosity of any colour should be such that, when mingled with its complementary colour, it gives a white *twice* as luminous as that at the centre of the circle. The same should be true of all other complementary pairs wherever situated. This appears to bear out the suggestions made at the end of Sect. 97; for, obviously, if each colour is halved in intensity before the two colours are mixed, the mixture will produce a white just equal in intensity to the white at the centre, provided the colours originally produce a white of double this intensity. (See also Sect. 263.)

245. *Circles of lower tone.*—The circle, being a plane figure, cannot exhibit changes in more than two variables, and those chosen are hue and tint. To show variations in shade or luminosity, we must take another circle, and place round its circumference an annulus of colours like those in the former circle, but of smaller luminosity. In this circle,

all the tints, and also the central white, will be darker. A series of such circles, each darker than its predecessor, may be formed.

246. *Colour Cylinder.*—A co-axial pile of such circles will form a Colour Cylinder, the upper face of which will contain bright hues and their tints, whilst the lower face may be practically black. The axis of the cylinder, as we descend, will pass from white through gray to black.

247 *The Colour Cone.*—Now, as colours are darkened, the number of distinguishable tints diminishes (Sect. 199), so that the lower circles may be made progressively smaller, till they at length end in a point, representing blackness. The Cylinder thus becomes a Cone. This cone is analogous to Lambert's pyramid, described in 1772.

The circumference of the base of such a cone is that of a chromatic circle. Within this circumference are a series of rings containing tints of the hues of the outer circle; these becoming paler and paler as the rings close in towards the central white point of the base. The axis of the cone is white at the base, and passes through gray to black at the vertex. As we ascend along a generating line of such a cone, we find the shades due to gradually reducing the luminosity of the basal circumferential hues, which are assumed to be of a normal average brightness.

A section, at right angles to the axis, gives us a circle, containing a series of annuli, which increase in purity of hue, as we recede from their central gray to the shade hues on the circumference of the outermost annulus.

The brightness of the colours is greater as we take the section nearer the base of the cone, where we assume the luminosity to be such as enables them to be most clearly distinguishable.

248. *The Double Cone.*—To make the system quite complete a second cone is needed, its base being placed against that of the first. It will be remembered (Sect 199)

that when the luminosity of colours is increased it becomes more difficult to discriminate them, just as it does when their luminosity is diminished.

Our second cone, therefore, has for its apex the brightest white which the eye can perceive. A circular section of this cone will have round its circumference a ring of brilliant colours, containing within it a series of annuli, showing the tints made by mixing these colours with proportions of white, increasing towards the centre. The colours diminish in luminosity, but increase in distinctness, as the section is taken nearer the base, until at length the basal section is the chromatic circle of normal luminosity and maximum distinctness of hue. It coincides in fact with the basal circle of the first cone just described. (Sect. 247.)

249. *Imperfections of the Cone.*—Such a double cone will contain every possible colour. There are some theoretical defects. It has been assumed that each of the (twenty) colours we started with occupies an equal twentieth part of the circumference of the basal circle, but this supposition is not a rational one, and the only way of determining the angular distribution of the colours is by referring them to their wave-lengths as found in the spectrum. Again, the cone does not furnish us with information as to the results of mixing colours which are not complementary. It would of course be practically quite impossible to construct this cone. Our best pigments do not properly represent the colours of the spectrum, all the colours they reflect being more or less impure, and it would be necessary for the production of even a single chromatic circle, that the pigments should be right in hue luminosity and purity.

250. *The Pyramid.*—In the colour pyramid or tetrahedron, red green blue and black are assigned to the four solid angles, white is assigned to the centre of the face opposite black, and gray to the geometrical centre of the figure. Along the edge joining blue and red will occur purple, and, similarly, between the blue and green will be

found marine, and, between the red and green, yellow. That face of the pyramid, which has the red blue and green angles, is really a colour triangle, and so is any section parallel to this face. (Sect. 257.)

251. *Benson's Colour Cube, based on the three primaries.* —Mr. Benson's ingenious Colour Cube deserves a brief description. In this, the three primary colours, red, blue, and green, are taken as the basis. At one solid angle of the cube is placed black, at the diagonally opposite angle, white. At the three corners, nearest to black, are placed full red, full green, and full blue, respectively, and in the corresponding corners, nearest to white, and diagonally opposite to the first three, are placed the secondaries, marine, purple, and yellow. The geometrical centre of the cube is occupied by gray, midway between white and black. The three faces of the cube, which meet at black, are called the faces of no red, no green, and no blue. The faces parallel to these are called the faces of full red, full green, and full blue, and intermediate parallel planes have intermediate intensities of these colours. The colour of any point in the cube will be compounded of red green and blue in proportion to the distances of that point from the three faces of no red, no green, no blue.

From the construction of the cube it follows that every straight line drawn through it will pass through a uniform gradation of colours; and also that the gradations along all parallel lines will be of the same nature. For instance the edge, joining black to red, and any line parallel to it, will pass through a series of colours differing from one another only by a constantly increasing amount of red. The diagonal (of the no blue face) joining black to yellow, will pass through all shades of yellow, that is through all shades of the resultant colour of red and green, and any line parallel to this diagonal will pass through colours differing only in the amount of yellow they contain. The cube diagonal, joining red to marine, will pass through all colours produced by a

mixture, in which red regularly decreases, and blue and green regularly increase. At the middle point of this diagonal the colour will be gray, showing that red and marine (blue with green) are complementary. The middle point of the line, joining the places of two given colours, is the place of their mean colour, e.g. orange is midway between red and yellow. The colours at the ends of any line, passing through the cube centre, and bisected by it, are perfect complementaries, and the middle point of the line is the position of gray.

The edges, joining the primaries with black, pass through shades or lower tones of these primaries. The edges, joining the secondaries with white, pass through the tints made by adding white to these secondaries. Of a line, through the centre of the cube, perpendicular to the faces full green and no green, the former half passes through shades of tints (gray plus the colour) of green, and the latter half through shades of tints of purple.

The no blue face will contain an orderly group of colours from which blue is absent. The opposite full blue face, will give the same colours modified by the addition of full blue to each of them, and a plane parallel to these faces, and half-way between them, will give the same colours modified by the addition of half of the full blue to each of them. Any section, at right angles to the black-white diagonal, will present an orderly group of all the colours possessing some equal degree of luminosity. Any two plane parallel sections, equidistant from, and on opposite sides of, the centre, will contain groups of colours complementary to each other.

Many other interesting relations may be pointed out, and it will be found that the Colour Cube will aid greatly in making harmonious and symmetrical colour designs.

Viewed from the standpoint of Analytical Geometry, the black corner is the origin of three axes (red, green, and blue), the red axis being the edge of meeting of the faces of no blue and no green, and so for the other axes. (Sect. 254.)

252. *Its imperfections.*—There are defects in the cube. For example, at the centre should be found, not gray, but white, if this point is to represent the colour due to mixing perfect complementaries; for the axis joining such colours passes through the centre. Again, it is assumed that the primaries are equal in brightness, and that they may be equidistantly placed; but both assumptions are incorrect. When we come to represent the coloured lights by pigments, we at once find that serious fresh difficulties arise, and that the hues, with their variations in tint and shade, cannot be made to coincide with the assigned theoretical positions.

253. *Classification on mechanical and geometrical methods.*—For arranging colours, Newton was the first to indicate a method in which mechanical principles were employed. He divided a circle into seven parts, proportional to the seven musical intervals, believing that such intervals represented rightly the proportions of his seven spectral colours. (Sect. 310.) At the centre of gravity of each of the seven arcs he placed a little circle of area proportional to the quantity of the corresponding colour. The position of the centre of gravity of any number of these circles indicates the nature of the resultant colour. A radius, drawn through this centre of gravity, points out on the circumference that spectral colour, which the resultant colour most nearly resembles, and the distance of this resultant colour from the (white) centre of the circle determines its purity.

254. If two colours be represented by straight lines drawn from a point, then it is easy to show (if the lines represent in magnitude and direction the quantity and quality of the colours) that the diagonal of the parallelogram, which has these lines for two of its sides, will represent the resultant colour in quantity (brightness) and quality (hue).

If we take any three lines through an origin as axes, and conceive these lines to represent the three primary colours, then the position of any other colour will be indicated by a point on a line through the origin; the co-ordinates of this

point, parallel to the axes, showing the proportions of the three primary colours which give by composition the resultant colour. The brightness is supposed to be zero at the origin and to increase regularly as we recede from the origin. (See end of Sect. 251.)

255. *Centre of Gravity Method.*—Colour charts may be constructed by treating the colours by methods analogous to those for finding the centre of gravity of two or more weights. Select two colours (say red and green), and let them be as nearly as possible of the same luminosity. Place one at one end of a straight line, and the other at the other. Then, if equal quantities of each colour are mixed, the position of the mixture-colour (yellow) will be at the middle of the line; and, if it contain half the red and half the green, it will have a luminosity the same as that of either of its components. If the mixture is made of seven of green and three of red, the greenish yellow obtained will be again of the same luminosity, but its position will be, not at the middle, but at three-tenths of the length of the line measured from the green end. In a similar way we can obtain positions of the colours due to mixtures of red and green in any other proportions.

256. The colours can easily be mingled in any required proportions by means of rotating discs, as explained in Section 78. The mixtures, so produced, can be copied, and the copies arranged along the line. If we wish to include other colours, and also the tints produced by mixing colours with white, we must employ three colours, and we may (with Maxwell) take vermilion-red, emerald-green, and ultramarine-blue. These may be placed at the corners of an equilateral triangle. (Plate VI., and Sect. 257.)

257. *The Colour Triangle of Maxwell.*—Maxwell chose the red green and blue, just mentioned (Sect. 256), because they approximately represented the primary colours, and placed them at the corners, R, G, B, of an equilateral triangle. (Plate VI.) Along the side joining red and green will occur

all the colours due to mixing red and green, yellow occupying the middle point. Similarly, between red and blue will occur all mixtures of those colours, with purple at the middle point; and, between blue and green will be found all mixtures of those colours, with marine at the midway point. A careful experiment is now made to determine the proportions in which red green and blue should be mixed by rotation in order to give a neutral gray, such as can be exactly matched by a gray produced by rotating black and white. In the red-green side of the triangle a point is then found corresponding to the position of the mixture of the amounts of red and green used. This point is the position of the complement of the fundamental blue. Joining B with this point in R G, we again determine on this new line the point which is, as it were, the centre of gravity of the quantities of the three colours, and this point in the triangle is the position of white. The mixture of the red blue and green used gives a gray, not a white, and in Maxwell's experiments this gray was about $3\frac{1}{2}$ times less luminous than white, so the coefficient $3\frac{1}{2}$ has to be introduced to correct this defect.

258. *The same.*—To determine the position of any other colour, say, chrome yellow, a disc painted with it, is combined with a green and a blue disc in such proportions as to give a neutral gray, matched by a black and a white disc.

The equation obtained was:

$$27\ Y + 12\tfrac{1}{2}\ G + 60\tfrac{1}{2}\ B = 32\tfrac{1}{2}\ W + 67\tfrac{1}{2}\ Bk.$$

Correcting for the gray to white, we get:

$$27\ Y + 12\tfrac{1}{2}\ G + 60\tfrac{1}{2}\ B = 114\ W.$$

But there are 14 more units of colour on one side than on the other of this latter equation. This shows us that the yellow is more intense than the fundamental colours, and we must raise 27 to 41 to equalise matters. This is done by giving yellow a coefficient $1\frac{1}{2}$, instead of the unity coefficient we started with. Now determine on the B G side

of the triangle a point corresponding to the mixture of $12\frac{1}{2}$ G and $60\frac{1}{2}$ B (which we know is the colour complementary to the yellow), and through this point, and the white point, draw a line of such a length that 41 parts of yellow, placed at its end, will balance about the white point the 73 of blue and green situated at the point determined in the B G side of the triangle.

It will be found (supposing each side of the triangle to be divided into 200 equal parts) that the chrome yellow is distant from the white point by $167\frac{1}{2}$ of such parts. It thus falls far outside the triangle, a fact that indicates that it cannot be made by any mixture of the red and green used, and that chrome yellow is far more saturated and intense than any yellow that can so be formed. The yellows lying on the side R G, and formed by mixing the red and green, are much paler and less saturated. (Sect. 125.)

259. *The same.*—The positions of other pigments can be similarly determined. Colours, actually producible from two fundamentals, lie along the sides; those, producible from the three fundamentals lie within the triangle; those, not producible, on account of their too great luminosity or saturation, lie outside the triangle; this being the case with those colours (such as chrome-yellow, etc.), which must be mixed with one of the primaries in order to enable them to match a mixture of the other two primaries. The chrome-yellow requires some blue, in order to enable it to match a mixture of the red and green lights of the pigments used.

The colours along the sides of the triangle are nearer the white than are the fundamental colours at the angles, and this indicates, in a geometrical manner, the fact that the mixture of two colours is paler or less pure than are its components. The complementary colours of the triangle are placed opposite one another; and, along any line, joining any point of any side with the central white, are placed colours mixed with more and more white, as the white point is approached; such a line in fact runs through a series of tints.

260. *The assumptions involved. Predictions.*—The angular position of the colours is to some extent arbitrary, being determined partly by the rotation experiments, and partly by the particular red green and blue chosen as fundamental. A change in these will change the others. Also the assumption that vermilion emerald-green and ultramarine have equal intensities is unfortunately far from true.

Notwithstanding these drawbacks the colour triangle is very valuable. It gives a certain precision to our ideas, and the science of colour becomes more quantitative and less qualitative. We can also by means of the triangle predict the result of mixing any two colours it contains, for example, red and bluish-green in equal quantities. Draw a line joining the positions of these colours, and its middle point will be found near the line joining purple and white, from which we infer, and correctly, that the result of mixing red and bluish-green will be a whitish purple. We can go further and find the result of the mixture of more than two colours. Choose any two of the given colours, join their positions by a line, and ascertain on this line the point which is the position of their mixture tint; join this point with that of the third colour, then the compound colour will lie somewhere in this line.

261. The triangle can also be constructed from observations made on coloured spectral lights by means of Maxwell's Colour-box. (Sect. 74.) In the case of colour-blind people (Part. VIII.) the form of the triangle will be a good deal altered, and if the colour-blind person is *strictly* bicoloriperceptive, the triangle reduces to a straight line. (Sect. 168.)

262. *Rood's reconstruction of Maxwell's Triangle.*—Prof. Rood has reconstructed the colour triangle, introducing coefficients which represent the actual luminosities of the same three fundamental colours; luminosities, which, in Maxwell's triangle, are taken as equal. It results that the position of white is removed from near the centre of the triangle to a point close to the side R G, and nearer to G

than to R. The angular positions of the derived colours and of various pigments are largely altered, and the coefficients also are changed in value. (Plate VI.)

263. *The Saturation Diagram.*—Prof. Rood has also constructed a very ingenious saturation diagram, in which all the colours on a certain circle are considered to possess equal saturating power, each of them producing with its diametrically opposite complementary a white, identical with the white produced by any other two diametrically opposite colours. (Sect. 244.)

The positions, on a circle, of a certain green, red, and blue, of equal saturating power, were determined; and then the places of other colours were ascertained by the method of rotation, the angular position indicating hue, and the distance from the central white measuring the saturation. Unfortunately, when we come to compare pigments, although we may know that, of a pair, one reflects an amount of coloured light, which will saturate, or make white with, the coloured light from the other, we do not know whether both reflect equal amounts of white light.

264. The extreme difficulty of realising a perfect colour-chart will be gathered from the details brought forward in this Part.

PART XII—DESCRIPTION OF CERTAIN COLOURS AND PIGMENTS.

265. *Retiring and Advancing, Cold and Warm Colours.* —Colours are often spoken of as retiring or advancing, and also as cold or warm. The advancing colours, in order of luminosity, are, first, yellow, then orange, then red. The retiring colours are their complementaries, blue, greenish-blue, marine. (Plate IV.) The above classification is not to be taken as more than a generalised statement of the fact that red and yellow colours appear to come forward when associated with blue and green ones.

The warm colours have a maximum in the red, and range from greenish-yellow, through yellow, orange, red, and crimson, to red-purple. The cold colours have a maximum in the marine, and range from yellowish-green, through green, bluish-green, marine, greenish-blue, and blue, to violet. (Plate IV.) These distinctions are founded, partly upon natural associations, partly, no doubt, upon scientific bases. The warm colours, for example, represent more than two-thirds of the luminosity of the coloured elements of white light. Red and yellow naturally suggest fire and flame; so also water and ice may be suggested by green and marine.

Tennyson recognises the warmth of red and yellow:—

> "Deep tulips dashed with fiery dew,
> Laburnums, dropping-wells of fire."

Again:

> . . . .
>
> "Unloved, the sun flower, shining fair,
> Ray round with flames her disc of seed."

The colours used for the vestments in the Roman, and to a less extent in the Anglican, Branch of the Church Catholic, illustrate very appropriately the influence of association. White is used on Festivals, except in the case of Martyrs. Red on Pentecost, and on Feasts of Apostles and Martyrs. Purple, or violet, in Advent and Lent. Green on Sundays and Ferias from Epiphany to Lent, and from Trinity Sunday to Advent. Black on Good Friday, and in Requiem Masses.

266. *Composition of obscure colours.*—To ascertain the real hue of any given obscure colour, such as a darkened dulled or reduced primary or secondary (Sects. 136, 236), we can examine it with the spectroscope, which will reveal the constituents. Or, we can try to imitate it by mixing with white gray or black various known colours, until we find a positive colour, or a combination of positive colours, which, thus diluted, resembles the given obscure colour. Or, we can endeavour to find a colour complementary to the given colour, that is, to find a known colour, which will produce with the given colour a gray, and we can then infer the nature of the obscure colour, because it will be complementary to the known colour. (Sects. 132-6.)

The following is an example of the way to find, by the method of rotation, the character of the rather indefinite colour of a piece of light brown paper. The paper was cut into a circle, and mounted on the same axis with four larger circles, black, white, yellow (gamboge), and red (vermilion). A practically exact match was produced when the sectors of the larger circles were taken of the angular magnitudes, 52 black, 15 white, 15 yellow, and 18 red. This shows that the small circle was really a grayish orange, a tertiary dulled. (Sect. 156.)

A piece of very dark brown paper was in a similar way matched by 10 white, 5 orange, 2 emerald-green, and 83 black, showing that its colour was a much dulled gray orange with a tinge of green.

Another piece of medium brown paper (used for the wall-lining of Mr. Pyke Thompson's "Turner House" at Penarth) was matched by rotating a disc compounded of $8\frac{1}{2}$ gamboge-yellow, 11 vermilion-red, 8 white, and $72\frac{1}{2}$ lamp-black. This paper is therefore a much dulled orange, and has a subdued and pleasant warm hue. (327A.)

In the trials for matching, an interesting point came out. I first tried to match the brown colour by rotating a sector of brilliant cadmium-orange with white and black sectors in various proportions, but failed. Now, as the match was obtained, when vermilion and gamboge were substituted for the orange, I inferred that no mixture of gamboge and vermilion would match the cadmium-orange, and trial fully confirmed this; the rotation orange of the yellow and red being much less brilliant than the simple orange pigment. (Sect. 268.)

Heliotrope colour may be very well imitated by a rotating circle composed of three sectors, 50 cobalt, 25 white, and 25 carmine. Beautiful "electric" and "peacock" blues are produced by rotating a circle containing cobalt blue and emerald green sectors. Terra cotta colour results from a circle half black and half red (the red being a wash of carmine over vermilion). A very pale sort of citrine gray was matched by a mixture of $42\frac{1}{2}$ black, $13\frac{1}{2}$ emerald green, 5 gamboge yellow, and 39 white. (See also Sect. 100.)

266A. *Pigments generally.*—Some authors define a pigment as a coloured substance in powder, and a paint as a pigment mixed with some medium. I have not observed this distinction. The pigments used by the ancient painters were derived mainly from native earths, and hence were extremely permanent, though their number was somewhat limited. Most of the pigments now used are artificial products made by means of our chemical knowledge.

Pigments may be classified, according to their origin, in three divisions, those obtained from the mineral animal or vegetable kingdom respectively. Among mineral pigments some are native, as cinnabar, lapis-lazuli, ochre, umber,

sienna, etc.: others are artificial, as vermilion, artificial ultramarine, chrome yellow, emerald green, etc. Iron furnishes the basis for a large number of pigments, reds, browns, etc., and is the great colouring material of Nature, almost all rocks owing their colour to iron. Copper furnishes several blues and greens. Lead enters into the composition of chrome yellow, flake white, etc. From the animal kingdom come carmine derived from cochineal, Indian yellow from the camel, sepia from the cuttle fish, etc. From the vegetable kingdom we get madder, gamboge, indigo, lampblack, the various aniline colours, etc.

The effect of immersing a pigment in a medium has been described in Sect. 36. Much richer effects are possible with oil than with water. Water-colour is the more delicate, and is well suited for atmospheric effects. (Sect. 324B.) Delicacy and depth of colour are somewhat antagonistic qualities and cannot co-exist to any great extent. Transparency is an essential, if we use a pigment of glazing. Opacity, on the other hand, is useful if the pigment is intended to express a high light. In oil-painting the artist produces his tints by mixing his pigments with some white pigment. In water-colour he can either do this or spread the paint in thin washes over white paper. The importance of the translucency or opacity of pigments has already been referred to. (Sect. 36.) Vermilion emerald-green and flake-white are usually considered too opaque for water-colour work, though they can easily be used for oil-painting. It is obvious that in a transparent pigment the light passes *twice through* it, so that the colour is richer, and purer from white light, than is the case in the colour due to a nearly opaque pigment. With oil-paints the effects of the medium persist, a dry film of oil being as refractive as a fluid one; but with water-colours, the medium of course vanishes by drying, the colours become more opaque, and change somewhat in hue.

In mixing pigments in order to produce new colours, there is inevitably a loss of light, and the brightness of the mixture is less than the mean brightness of its constituents. (Sects. 83, 120.)

For details respecting coloured glasses reference may be made to Sects. 16-22.

267. *Red.*—The normal spectral red is fairly well represented by vermilion washed over with carmine. Red of low luminosity, or mixed with much black, gives a series of browns, the deeper ones being chocolate-coloured. With a smaller quantity of black, terra-cotta colours are produced. Ordinary carmine is purplish, that is to say, it contains some blue. Red is less bright than yellow, but is warmer and more retiring. Many red paints reflect orange as well as red. Some red glasses transmit orange ; but two or three thicknesses will often give an almost pure red beam. Vermilion, red ochre, cochineal lakes (carmine, etc.), red lead, Venetian and Indian red, aniline scarlet, madder lakes, are examples of red pigments. Except the scarlet iodide of mercury, vermilion is the most brilliant red we possess.

When mixed with white, red gives light red and pink, with gray, russet and maroon. Mixed on the palette with yellow, red gives orange (not brilliant), with green, dull browns, with blue, or violet, dull purples.

The following are some of the terms used in describing different reds, rose, brick, scarlet, blood, flesh, carmine, crimson, cherry, cardinal, terra-cotta, coral, salmon-pink, poppy, Indian, cerise-pink, russet, maroon.

268. *Orange.*—This colour passes to orange-red on the one side and orange-yellow on the other. It is a bright warm and advancing colour, in this resembling yellow. If we mix red and yellow pigments, we should—to make a good orange—use a reddish yellow and a yellowish red, but the orange made by palette mixture is never so brilliant as a bright natural orange pigment. (Sect. 266.)

Cadmium, burnt sienna, Mars orange, aniline orange, and orange chrome, exemplify the orange pigments. Rotated with black, orange gives brown, if reddish, or olive-green, if yellowish ; with gray a russet, with white a paler orange, or

a buff. Mixed on the palette with green, orange gives yellow and light olive greens, with blue, dull greens and dark olive greens.

269. *Yellow.*—This is the most luminous and advancing of colours. The brightness of most yellow pigments much exceeds that of red green or blue pigments. Besides pure yellow, a good deal of the spectral colours (red and green) is reflected to the eye by yellow pigments, so that the yellow seen contains both the simple and compound colour. (Sect. 125.) Yellow glasses transmit red and green as well as yellow. Chrome, lemon-yellow, aureolin, gamboge, yellow-ochre, raw sienna, aniline yellow, cadmium yellow, Naples yellow, Indian yellow, exemplify the yellow pigments.

Rotated with gray, yellow gives citrine; with black, olive-greens, and browns, if the yellow tends to red; with white, pale yellows. On the palette, mixtures of red and green yield dull browns or brownish yellows. Citrine and olive may be prepared by mixing on the palette green and orange, and green and purple, respectively. Mixed on the palette with green, yellow gives yellowish greens; with blue, if the blue is a greenish one, fairly good greens; but if it is a more pure blue, the greens are dull.

Yellows may be distinguished as Indian, sulphur, straw, honey, ochre, lemon, primrose, cream, gold, canary, orange, citron, drab, stone, etc.

270. *Green.*—This colour in the spectrum is at one side yellowish, at the other bluish. Green, though a cold colour, is very intense, produces marked visual fatigue, and brings out strongly subjective complementary tints. (Sect. 211). Yellowish green is often seen in spring foliage, bluish green in the ocean. Emerald-green paint is not a pure green but contains a trace of blue. Green glasses cut off both ends of the spectrum, but often transmit orange yellow and blue in addition to green.

Mixed with black, white, or gray, green produces dark, pale, or sage, greens, respectively. With blue on the palette, green produces bluish-greens, marines, and greenish-blues.

To get a good green from yellow and blue pigments, each of them should contain a good deal of green, and be transparent to it; e.g. prussian blue and gamboge, which together form Hooker's green.

Oxide of chromium, chrome-green, emerald-green, malachite-green, verdigris, cobalt-green, Hooker's-green, aniline green, and green bice, are green pigments. "Brown-pink" is an olive green.

Greens are distinguished as, verdigris, leek, emerald, oil, apple, grass, olive, siskin, electric, sage, myrtle, moss, reseda, holly, turquoise, cucumber, pea, peacock, eau-de-nil, malachite, etc.

271. *Marine.*—Marine is the hue between blue and green. It can be imitated by a mixture of cobalt-blue and emerald-green. Vert de cobalt, Prussian green, viridian, cerulean blue, Victoria aniline green, terre verte, are more or less marine coloured paints. Mixed with gray, marine gives a bluish sage colour. Marine is a decidedly cold colour. Some kinds of turquoise are bluish marine in colour. Peacock blue and green are also closely related to marine.

A great variety of colours, ranging from yellowish green through green bluish-green and marine to greenish-blue, and of shades of these colours, can be produced by palette mixing of various yellow, brown, green, and blue, pigments.

272. *Blue.*—This is less energetic in its action on the retina than either green or violet. It is a cool retiring colour. Genuine ultramarine is perhaps the purest blue pigment. Artificial ultramarine inclines to violet. Cobalt-blue reflects green and violet as well as blue, that is, a compound, as well as a simple, blue. Prussian blue and indigo contain a good deal of green.

Some blue glasses transmit nearly all the spectral colours except the yellow, but the red is darkened. With a greater thickness red and violet disappear, and only a little green remains besides the blue. Other glasses transmit a fairly good blue, containing usually however some green or violet or both.

Mixed with black, white, or gray, blue produces dark, light, or slaty, blues. The purples made by mixing on the palette blue and red are often very dull and poor. For other palette mixtures, see preceding Sections.

Ultramarine, cobalt, indigo, Prussian-blue, French or artificial ultramarine, aniline blue, etc., are blue paints.

Among varieties of blue are turquoise, peacock, electric, (all more or less greenish), azure, sky, lavender, cobalt, prussian, indigo, violet, etc.

It is very difficult to make pleasing pictures containing a large amount of blue or green, or of blue and green. Gainsborough's "Blue Boy" is said to have been painted to disprove this assertion; perhaps it may be said to prove rather the skill of the artist, who, like Opie, "mixed his colours with brains." The "coldness" and "hardness" of the blue-to-green colours are generally assigned as the reason for the difficulty referred to. (Sects. 284, 286, 289, and also 215.)

273. *Violet.*—This colour is best seen in the spectrum, where it occurs at the more refrangible end, and fades off into the darkness of the ultra-violet. It is stated that, with the exception of green, violet acts more powerfully upon the eye than any other colour; but violet pigments are dull.

There are no good violet pigments, unless we take the aniline colours which are too fugitive for use in pictures. Probably most violet aniline colours really contain some red, and so are somewhat purple. Mixed with gray, violet makes a lavender colour; with red we get purples. Among varieties of violet are purple, blue, and lavender, violet. Artificial ultramarine is a bluish violet, and when washed with Hofmann's violet BB fairly represents the spectral violet.

274. *Purple.*—Purple is distinguished from violet by containing red. It is physically, as well as physiologically, compound (red and blue, or red and violet), and is not in the spectrum. There are no very good purple pigments. The aniline dyes, which however cannot be used for pictures,

are the best examples of purple (e.g. mauve, Hofmann's "Violets," etc.) Purple madder and Mars violet are the only permanent purple pigments, and they are not rich colours. Tolerable purples may be made by mixing permanent reds and blues. But some reds and blues are so opaque to each other that the purple is very poor, e.g. ultramarine and vermilion. (Sect. 31.) Ultramarine, or cobalt, and madder laid over a white ground will give purple. Violet carmine is a beautiful but transitory blue-purple pigment. Crimson and purple lakes are reddish purples. Peach, almond-blossom, heliotrope, plum, and lilac are pale purples, that is purples mixed with white or gray. Very beautiful rose-purples are produced by mingling spectral red with the colours from blue to violet. Purple is a warm colour, but much less warm than red. It varies from blue-purple to red-purple according to the proportions of blue and red present. Pinks usually contain some blue, and may then be viewed as pale red-purples.

Purple of Cassius owes its colour to gold. The toga of the Roman Emperors was dyed with Tyrian purple obtained from shell-fish of the genus Murex. Ammonium purpurate, or Murexid, is an organic compound yielding beautiful purple dyes.

275. *Brown.*—This is a dark red or orange. (Sects. 267-8.) Umber, Vandyke brown, sepia, brown madder, bistre, and many preparations of iron, such as ochres, siennas, etc., are brown paints. Mixed by rotation with black, white, or gray, brown gives dark, light, and gray, brown. Among browns are reddish, clove, hair, chestnut, chocolate, coffee, liver, fawn, maroon, terra cotta, oak, nut, stone, golden, etc.

276. *Black.*—The black paints are represented by ivory black, lampblack, Indian ink, black-lead, etc., all derived from carbon. Even the deepest black reflects some white light from its surface, sometimes as much as 5 per cent. of the light that would be reflected from white paper under the same illumination. With white, black forms grays.

With positive colours in small quantities, we get greenish, bluish, brownish, etc., blacks. Black pigments washed over a white ground give grays of various tones. Some of these grays show traces of positive colour, such as brown or blue.

277. *White.*—For white pigments we have zinc white, white lead, baryta white, etc. The lead pigment is exceedingly opaque, but unfortunately is greatly apt to be altered (blackened) by gases containing sulphur. Zinc white is less opaque, but is permanent. With black, white forms grays. With small quantities of positive colours, we get reddish, yellowish, greenish, etc., whites. Sometimes whites are distinguished as pearl white, ivory white, etc. Of course pure whites are, theoretically, always alike.

278. *Gray.*—This colour results from a mixture of black and white. Among gray pigments are neutral tint, Payne's gray, ultramarine ash. Some grays are rather bluish. (Sect. 48.) For some experiments, connected with photography, Roscoe prepared a "standard gray" by grinding together in certain proportions zinc white and lampblack. The colours belonging to the dulled scale (Sect. 236) are often called "grays;" e.g. bluish, smoke, greenish, pearl, yellowish, silver, etc. Strictly speaking pure gray is the standard neutral tint.

278A. *Metallic Colours.*—Metallic colours (Sect. 45) are named from the metals they resemble: copper-red, bronze-yellow, brass-yellow, gold-yellow, silver-white, tin-white, lead-gray, steel-gray, iron-gray.

279. *Alteration of pigments by light, etc.*—Pigments are in many cases seriously altered, either by exposure to light, by the action of the atmosphere, by the action of the medium with which they are mixed, or by the action of other pigments mixed with them.

Many experiments have been made to determine what pigments give permanent colours. It is of the utmost importance to use only permanent colours for valuable

paintings. An examination of the pigments, used in some old Dutch paintings, revealed the fact that their permanence was due to the simplicity of the materials used—earths and minerals, and not chemical precipitates. The great victories which chemistry has won for the painter, by furnishing him with brilliant pigments, may be purchased at a perilous price, if the artist is not careful to see that the pigment is permanent as well as brilliant. Carmine, brown pink, indigo, Hooker's green, prussian blue, etc., are liable to fade, or to change in tint. The great artist willingly sacrifices the temporary triumph of dazzling fleeting colours for the permanent success of somewhat duller hues that will last unchanged through centuries. The old Dutch paintings, referred to, are by no means really dim ; take for example, the pictures of Jan Van Eyck, who lived early in the fourteenth century.

PART XIII.—COLOUR-COMBINATIONS. DYADS, TRIADS, ETC.

280. *Colours associated with White, Gray, or Black.*—This subject was referred to in Sections 207-210, under Contrast. With white, *red* becomes darker and purer. With black, it becomes brighter and tends to orange. With gray, red becomes richer, but its tone will depend upon the tone of the gray, being darker or lighter according as the gray is lighter or darker, and this action of gray is typical. *Orange* with black, or dark gray, becomes brighter and rather yellower. With white, or light gray, it is made deeper and slightly reddish. The contrast of orange and white is a good one. With white, *yellow* is slightly darkened and enriched. A light yellow and white do not form a pleasing combination. With dark gray, yellow is brightened and forms a good combination. With black, yellow is brightened, and the black becomes slightly bluish. With white, *green* becomes darker and purer, and forms a good contrast. With pale gray, it also looks deeper, and the gray becomes purplish. With black, green is brighter and purer, and the black becomes purplish. *Blue* with white is rendered richer and deeper in tone, and the contrast is a pleasing one. A good example is afforded by the blue sky seen through an opening in bright white cloud. The white sometimes shows a tendency to yellow. With black, blue is brightened, but the pair do not form a very agreeable combination. *Violet* with white affords a strong tone contrast, and the combination is a good one. With gray, violet forms a quiet and pleasant combination. With black, violet affords only a slight contrast. *Purple* makes a good

contrast with white, and pale purples and rosy tints associate well with white. Purple and gray form a pleasant combination; the gray looks greenish. Purple and black do not contrast well; the black becomes greenish.

It will be seen that *black* increases the apparent tone or *luminosity* of a colour. Along with this increasing brightness there will be slight changes of hue in accordance with the principles explained in Part IX. Does black increase or diminish the *purity* of a colour associated with it? Mr. Scott Taylor says that a colour, placed on black, appears purer than when placed upon a ground of its own colour. This may be the case with colours which are fairly saturated to begin with. But, when pale colours are placed on a black ground, they appear to me whiter, and (if very pale) even white. This effect is, I suppose, due to the tone-contrast overcoming the increase in purity said to occur. Prof. Church states that black *lowers* the apparent purity of a colour placed upon it. This statement exactly contradicts Mr. Taylor's rule, which I have provisionally adopted. (Sect. 210.)

A *white* ground certainly diminishes the luminosity and increases the purity of a colour placed upon it. *Gray* varies in action on the luminosity according to its own brightness. It is stated by some that gray always increases the purity of a colour, and, of course, if the black in the gray acts only on the luminosity, the statement will be true, for the white element of the gray increases the purity by contrast. But a dark gray will make a pale colour look nearly white. (See remarks on black.)

The whole subject of contrast seems to me to call for careful re-investigation.

The complementary colours called up (best upon gray) by contrast, are treated of in Sect. 211.

281. *Definition of a Dyad. Factors influencing the quality of dyads.*—Pairs of different hues may be divided into three classes; those in which the difference is *small* (to be treated

later on, Part XIV.); those in which it is *considerable;* those in which it is at a *maximum* (the complementaries). A Dyad may perhaps be defined as a pair of colours separated by more than the small interval. We know that certain pairs are very pleasing, e.g., red and blue, yellow and violet; others are displeasing, e.g., yellow and marine, red and violet, greenish-yellow and orange-yellow. No doubt helpful and harmful contrast (Sect. 216) has great influence on the result, but associations, inherited tendencies, our acquaintance with nature's colour-grouping, also play an important, though it may be an obscurely understood, part in determining our preferences.

In many cases the effect of the two associated colours is much improved by mixing one of them with black or gray.

282. *Influence of lustre, texture, etc.*—In estimating the effects produced by colours in combination, it is important to exclude all extraneous influences, such as those of peculiar materials, or patterns, gradation, light and shade effect, etc. Cloth paper and canvas are suitable materials for our experiments. Silk velvet glass and enamel introduce lustre, translucency, etc., and so complicate the results. Patterns, formed by the stained glass fragments of the kaleidoscope, are often very effective owing to their brilliancy, but may be of little beauty when reproduced in the duller colours of pigments. Colour-combinations on silk may be pleasing, owing to the lustre of the material, whilst the same colours transferred to wool or cotton may look poor.

283. *Dyads in Nature.*—We must be cautious in drawing our conclusions, even from observations based directly upon Nature. Green and blue make a poor combination, and yet we constantly see the blue sky through green foliage. But how different is this from the crude contrast presented by a piece of green paper laid upon a piece of blue! The sky itself varies in the depth of its blue, deepening from horizon to zenith. One leaf will be yellowish-green by transmitted light, another bluish-green by reflected light, another gray.

One will be brightly lighted (with a light far transcending that of pigments), another will be in deep shadow, another will exhibit exquisite gradations of tone or tint. Then there are the various forms and groupings of the leaves stems and branches.

Here we have hints as to what the artist should do to imitate nature. He must have varied outlines, imperceptible gradations of tone and tint, minute variations of hue, and must do his best to so adjust his pigments as to imitate, though he cannot rival, the light and shade of nature.

284. *Dyads and Contrast. Bad and good pairs.*—Several causes may make a dyad bad. Harmful contrast causes the pair to look dull and poor; helpful contrast, on the contrary, if in excess, may produce hardness or harshness. (Sect. 216.) In the chromatic circle (Sect. 139) colours, less than about 90° apart, suffer from harmful contrast (e.g. orange and red, yellow and yellow-green, green and marine); those, more distant, help each other; but it does not follow that those, furthest away (180°), *i.e.* the complementaries, always make the best combinations. Red and marine, purple and green, are considered harsh pairs of complementaries, for the contrast is at a maximum, not only in hue, but also in warmth and coldness. These dyads are therefore sparingly used.

On the other hand, the complementary pairs, blue and yellow, greenish-blue and orange, violet and greenish-yellow, are good, and are frequently used; the reason assigned being that, though contrasted fully in hue, the contrast is not enforced by an equally powerful opposition of coldness and warmth, but is tempered by the fact that in these dyads the colours, as regards coldness and warmth, are pleasantly balanced. It appears also that to produce the best effect between complementaries, the members of the pairs should be unequally bright, and this condition is much better satisfied by our second than by our first set. Black with white forms the greatest contrast we have.

A dyad may be poor if it contains no decidedly warm colour, for it seems to be a fact that the eye prefers compositions in which warmth predominates. (Sects. 265, 272.)

The following dyads are classed "excellent;" red blue, yellow violet, orange-red blue, orange-yellow violet, greenish-yellow violet. "Good" dyads:—red marine (rather strong), red green (hard), orange violet, orange marine, orange blue (strong), yellow purple, greenish-yellow purple, yellowish-green blue, marine violet, etc. "Fair" dyads:—red greenish-yellow, orange-red purple, orange green, orange-yellow bluish-marine, greenish-yellow orange-red, marine purple, etc. "Bad" dyads:—red violet, orange purple, orange-yellow green, yellow marine, yellow green, yellowish-green marine, green bluish-marine, marine blue, marine green, etc.

Colours may be well placed in the chromatic circle, and yet their pigment representatives may be far from giving the expected effect. For example, many yellow pigments are much too brilliant (Sect. 269), but we may (as Prof. Rood remarks) avoid harshness by substituting a modest yellow ochre for chrome-yellow, and so on.

It will be understood that there is much room for difference of opinion and taste in connection with the question of the degree of goodness or badness of certain combinations.

284A. *Intermediate Colours.*—The foregoing list does not include the intermediate colours produced by mingling colours with black white or gray. Such colours have been referred to in Sect. 236 (darkened reduced and dulled colours), and in Part XII., Sect. 266, etc. They are most valuable for ornamental and pictorial purposes, and are infinite in variety, and almost so in name; maroon, chocolate, garnet, red, salmon-pink, rose-gray, amber, straw, fawn, citrine, lavender, lilac, plum, puce, russet, sage, buff, slate, olive, etc., etc.

285. *Dulled Complementaries.*—Complementary colours, when the colours used are dull or pale, are often very valuable for artistic purposes. For the dullness prevents

all danger of harshness, whilst the fact of the colours being complementary excludes all risk of either damaging the brilliancy of the other. The harsh pairs, red and marine, purple and green, may be so tempered as not to offend the eye. Modified complementaries have been referred to in Sect. 132. Complementary pairs of the dulled hues known as "Tertiaries" (Sect. 156), can be freely used with good effect; e.g. amber and pale gray turquoise. (Sect. 136.)

286. The difficulty of managing greens and bluish-greens has already been referred to. (Sect. 272.) Green is intense and yet cold, red conveys the idea of warmth, yellow that of light. A slight excess of yellow or red in a picture is far less injurious than a little too much green. In power of exhausting the eye colours stand thus, according to Rood, green, violet, blue, red, orange, and last and least, yellow. Green seems to exceed all other colours in its power of calling up accidental or complementary images. (Sect. 211.)

287. *Improvement of bad dyads.*—A harmful contrast effect may be mitigated by darkening one of the colours, or by assigning it a much smaller field than its rival. A poor or bad dyad may also be improved by adding a third colour, thus forming a triad; whilst a good dyad may be injured by introducing another colour. Greenish-yellow and blue form a good, greenish-yellow and greenish-blue a bad, dyad; violet injures the former, but improves the latter. (Prof. Church.)

288. *Triad defined. Triads, with white, etc.*—A Triad is a group of three colours separated by more than the small interval. The study of triple colour combinations is a difficult one. We may begin by cases where one of the three colours is white black or gray. If there are two nearly related colours, such as violet and deep blue, which are cool and retiring, white will form with them a much better triad than black. For the deep tones of blue and violet are in their low luminosity near to black, so that they are not

much relieved by it, whilst the black itself acquires a rusty hue owing to the subjective complementary being called up. White, however, whilst it deepens the colours, purifies them, and, by itself acquiring a faint complementary tinge, brings them out distinctly. Gray has a still better effect than white, as the tone-contrast is gentler. (Prof. Church.)

289. *Triads and the chromatic circle.*—Generally speaking, good triads may be made by choosing colours from 90° to 150° apart in the circle. It is stated that the triads most extensively used are—red, yellow, blue; purple-red, yellow, greenish-blue; orange, green, violet; and orange, green, purple-violet. In the first of these the yellow is rather too near the red, but the blue balances this defect. In the second, the colours are almost exactly 120° apart. In the third, orange and violet are about 90° apart, but are further from the green, and combine well with it. (Plate IV.)

It appears that, as a rule, in good triads two out of the three colours are warm hues. The desire to satisfy the laws of contrast, and to secure the presence of warmth, greatly limits the number of good triads. Carmine with yellow and green is said to have been used a good deal in the middle ages. This triad has two warm colours, but the contrasts carmine-yellow and yellow-green are not good, and there is a hardness in the contrast carmine-green. Vermilion with olivegreen and ultramarine is a triad frequent among Italian painters. (Veronese, etc.) The contrast vermilion-olivegreen is rather hard, the other pairs are good, but there is a little want of warmth. Orange-yellow with violet and bluish-green is a triad which is poor, not from defect of contrast, but because it contains two cold colours, the bluish-green being specially cold. (Sects. 265, 272.)

290. *Complex Combinations.*—By adding to the triads white gray or black, or by using tints shades or broken tints, of the original hues, various complex combinations can be formed, which are too elaborate to be here discussed. But if we are able to use choice materials, such as silk or

enamel to receive our colours, it will often be found that two or three hues are as effective as half-a-dozen, for the influence of pattern, lustre, surface, texture, etc., will come into play. (Sect. 282.)

291. *A Dominant Hue.*—Usually, when three or more colours are associated, it will be found that, for a good result, some one of them must predominate over the rest. Prominence may be given to the selected hue by increasing the area it covers, or by strengthening its purity or luminosity, so that there shall be an excess of some positive colour.

292. *Balance of Colour, optical and aesthetic.*—It has been argued, by Field and others, that, in a chromatic composition, the best effect is obtained if the relative areas of the different colours are such that a neutral gray would result from mixing them all together. Such a theory assumes that optical and aesthetic balance are one and the same. The supposition is not true. Almost all satisfactory colour-combination is characterised by some dominant hue, some excess of some one colour, and usually of some warm hue. With Maxwell's discs, a good gray may be obtained by means of red green and blue in certain proportions; but it does not at all follow that a picture, in which these colours occurred in the same proportions, would be artistically pleasing.

Field, basing his researches on Brewster's faulty theory (Sect. 157), asserted that a neutral gray resulted from mixing five of red with eight of blue and three of yellow, and that such should be the proportion of these colours in an artistically optically balanced picture. This is Field's doctrine of "chromatic equivalents."

Here, besides his erroneous supposition that the optical and aesthetic balance are equivalent, there is a serious error of fact, for the neutral gray does not result from true mingling of the three colours named, though, by the totally different process of adding their absorptive powers by mixing them on a palette, a dull grayish brown might be obtained.

It often happens that colour-combinations are devised which are not intended to stand alone. For example, a blue and white jar may receive the colour, necessary to make a chromatic balance, by the panelled brown background against which it is seen. So also the bad effect produced by filling a large unbroken space with some one colour, may be quite altered by distributing the coloured area into small portions over some ornamental pattern.

292A. *Picture frames.*—The following valuable remarks are most kindly contributed by Mr. T. H. Thomas R.C.A., whose life-long devotion to Art entitles him to speak with authority.

[The ideal of picture-framing is the most perfect attainable isolation of the work from surrounding objects by means of some hue which shall best develope (*a*) the light and shade, (*b*) the colour, of the picture. This object is more or less attained by surrounding the picture with surfaces of white, tints of gray, low tints of colour (such as olive or russet), black, or gold either burnished bright or mat. The more delicate the colours of the picture the more suitable are tints of gray to bear them out, a middle tint being, upon the whole, best; one which increases, by its slight contrast of depth, the lighter and brighter colours, while deepening by opposition, those richer and darker. For large and strong works (such as pictures painted in oil, or in water-colours when marked effects of light and shade are aimed at), frames of black, or more frequently gilded, have been almost universally used.

Many works of the German, Flemish, and Dutch Schools have been framed in black wood, either polished or dull, often with a narrow inner line of gold. Such frames may be seen represented frequently in paintings of Dutch and Flemish interiors. For strictly artistic effect of the picture this kind of frame can hardly be surpassed, the black wood affording to the eye a very dark gray, against which the colours and values of the various parts of the painting yield their fullest harmony and beauty.

Next to black, plain gold surfaces seem best for the isolation of colours, and the beauty of the metal, its richness and opulence of hue, with the associated sense of wealth and luxury, have made the gilded frame almost universal. Its advantage is the gorgeousness of effect it lends to galleries and rooms; its disadvantage the brilliance, which detracts from the effect of the work it surrounds. The injury done is the more evident when the frame consists of many mouldings, and when the decorations are burnished, or the sides project boldly. When such cases are strictly analysed, the picture will be seen to suffer considerable loss of purity, harmony, or delicacy of gradation; accordingly, it is within the experience of most observers that paintings in gold frames, which have been dulled by time, are seen to greater advantage than they were when the frames were fresh.

Many artists have applied themselves to the minimizing of the ill effect of the ordinary gilded frame. Perhaps the most successful result is associated with the name of the celebrated painter Sir G. F. Watts, R.A. In his arrangement, the painting is surrounded by a narrow flat, followed by a slip of ornamental moulding in moderate relief, then comes a wider flat of gilded oak, bordered by a rising moulding of acanthus.

No other form so well combines the qualities of richness and simplicity, or diminishes to the same extent the metallic flash from the frame, which is so injurious to the effect of the picture. Other devices may be seen, more often in Continental galleries than in our own, where gilding of varied tints is used, or where the gilt is reduced in tone by the application of pigments, or the frame is painted to represent patinated bronze, or other substances of broken hue and low tone].

PART XIV.—THE SMALL INTERVAL AND GRADATION.

293. *Gradation, when natural, is good.*—When identical colours (such as red and orange-red) are associated, each is made by contrast to appear less saturated or intense. It might therefore be supposed that it would not be allowable to place near together such colours. But in practice it is found that, under certain conditions, colours, distant on the chromatic circle by only a *small interval*, can be associated without detriment. If the two colours express by their change of hue a variation of luminosity in the *same* coloured surface, they do not come into hurtful contrast. A soldier's cloak appears orange in the sunshine, but red in the shade; grass looks yellowish-green in the sunshine, but bluish-green in the shade. So changes of hue of this kind in associated colours are all right, if we can view them as produced by different amounts of illumination. Two adjacent hues should therefore have their luminosities so arranged as to correspond with nature.

The spectrum furnishes beautiful examples of gradation: red to orange-red, orange-red to orange, orange to orange-yellow, orange-yellow to yellow, and so on. We observe an almost imperceptible passage from one colour to another, which produces a pleasing impression. If we select all the hues in any given portion of the spectrum, it will generally be found best to use them in spectral order.

294. *Discontinuity, and the value of neutral elements.*—If, however, we choose from the spectrum three separate strips, lying near together, so that there are little jumps between the colours, the effect of placing such colours in

contact is not very satisfactory. They do not imperceptibly gradate, and yet they are not sufficiently distinct from each other. Separating narrow lines of neutral elements, white, black, or gray, are needed to accentuate the differences, and then the combination is pleasing. Such an arrangement would occur as a rule only in decorative art.

295. *Examples, from Nature, of gradation.*—One of the commonest of the small intervals is that of yellow deepening into orange-yellow. In sunsets this gradation is well seen, and also in yellow flowers and the subdued yellowish browns of many natural objects. Foliage in sunlight and shade shows beautifully the changes from yellowish-green to green and bluish-green; whilst the interval from greenish-blue to blue is grandly displayed by the sky. Orange-red to red, and red to purple, are constantly seen in connection with sunsets. (Sect. 283.)

296. *Rapid transitions between remote hues.*—If colours are quite distant on the chromatic circle (Sect. 139), a rapid transition from one to the other produces a disagreeable effect. Yellow contrasts well with blue, but if it passes by quick gradations into blue the effect is bad. Again, if the cool gray of a cliff suddenly changes into red, we want an explanation, if the effect is not to be displeasing. If we know that the red part is lighted by the setting sun, or if it is invaded by veins of some ferruginous mineral, then we feel satisfied, for the strangeness is accounted for. (*Rood.*)

297. *Importance of gradation for pictorial art.*—For pictorial art the value of pure gradation of hue cannot be overestimated. It is akin to modulation in speech. In nature, gradations are infinite and marvellously subtle, and the truly great artist is he who can imitate them so far as to reproduce something of the tenderness, variety, and mystery, of the reality. Even a specially prepared uniformly coloured surface will not appear uniformly coloured, unless the illumination of it be artificially arranged; and natural objects are neither uniformly coloured nor uniformly lighted.

Our unconscious sensation is immensely in advance of our conscious ; we recollect sensations wonderfully well, but not the causes that produce them. An ordinary person would at once see the want of truth, which absence of gradation produces, but he would not be able, like the artist, to account for the strange appearance.

Long training and clear insight into causes are required to produce results which we can passively enjoy in happy ignorance.

Paints, when in use, being fluid, the colours can be made to flow into one another, and in this way gradation and softness are obtained whilst hardness is avoided.

298. *Rood*, *Ruskin*, *Turner.*—[The ever present changes of colour in all natural objects give to the mind a sense of the richness and vastness of the resources of Nature. There is always something more to see, some new evanescent series of delicate tints to trace, giving a sense of fulness, and a dim perception of the infinite series of gentle changes by which Nature constantly varies the aspects of the commonest objects. The true Artist strives to imitate all this, and relies for his triumphs far more on gradation than on contrast.—*Rood.*]

[Gradation is to colours what curvature is to lines, both being felt to be beautiful by the pure instinct of the human mind, and both, as types, expressing the law of gradual change and progress in the soul itself. What the difference is, in mere beauty, between a gradated and an ungradated colour, may be easily seen by laying an even tint of rose-colour on paper, and putting a rose-leaf beside it. The victorious beauty of the rose-leaf depends upon the delicacy and quantity of its colour-gradations.—*Ruskin.*]

To this, I think, should also be added the effect of the cellular texture of the leaf. All great colourists have excelled in gradation, and their works, when viewed from a proper distance, are "tremulous with changing tints." Turner is famous for his mastery over and use of the principle just

dwelt upon. The sky is perhaps our best example of slow continuous change of colour. Its perfect gradation indicates its peculiar qualities as a gas ; " it is impalpable, evanescent, boundless."

299. *Two kinds of gradation, orderly and mixed.*—In the first, or orderly, kind of gradation, there is a constant succession of tones of the same colour, or of closely related colours, arranged in orderly sequence, as in the clear sky just referred to.

In the second, or mixed, kind, the same tones are so placed together as to mingle by adjacency (Sect. 106) more or less perfectly on the retina, and thus produce a peculiar tremulous or palpitating effect, due probably to one colour or other predominating in turns. We seem to see into the colours, and lustre is added to colour. This effect is most marked with complementary colours. Binocular vision also comes into play, two slightly dissimilar pictures being presented to the two eyes, and giving an appearance of transparency. (Sects. 107-109.)

300. *Stippling, scene-painting, etching, etc.*—The beautiful effects, just referred to, are produced by painting fine lines or dots of different colours close together. When dots are used the process is called stippling. In wall-papers carpets and cashmere shawls, use is made of this method of mingling colours by adjacency. So too in etching, the dark and light lines blend together. In scene-painting, meant to be viewed at a considerable distance, what appears, near at hand, a mere confused mass of daubs, becomes, when we retire from it, an effective picture.

301. In a distant sea, under sunshine, the waves may be green, the spaces between them bluish ; the blue and green will blend into a sparkling marine tint, which no single pigment can imitate.

In early spring the leafless branches of the elm seem wrapt in a delicate pinkish cloud—a result of the adjacency mingling of innumerable tiny flowers ; and in autumn the

moorlands glow with a subdued purple tint, due to the mixture by adjacency of the countless bell-like blossoms of the heather.

Scumbling and glazing are often effectively used to give the appearance of atmosphere and transparency, and to imitate peculiar textures. The texture of the paper or canvas is also of great assistance for the same purpose, and so also are the different kinds of brushes, and the various methods of handling them.

Mr. Alma Tadema's superlative skill in imitating the lustre and texture of marble is quite beyond praise.

302. *Pictures in Monochrome.*—Pictures may be painted in monochrome, or with very dull or pale colours; but here great use is made of the small interval, and of light and shade; and by this means very beautiful and natural results are obtained.

303. *Gradation and Decorative Art.*—In decorative art, blending or gradation of colours is of subordinate importance, the colours being usually separated by sharp outlines, often traced in black white gray or gold. Gradation being one of the most efficient modes of producing a realistic appearance, it evidently cannot be much employed in ornament, where we wish to avoid intentional realism.

As a beautiful example of the use of the small interval in decorative art, Prof. Church instances some old Faience, in which the patterns, outlined in deep cobalt blue, are filled in, partly with turquoise, and partly with lavender. Here we have different tones of three related hues, rich deep blue, medium greenish blue, and pale grayish blue.

PART XV.—HARMONIES OF COLOUR.

304.—*Chevreul's Harmonies.*—Chevreul's arrangement of Colour Harmonies is as follows. (I). Harmonies of Analogy. First of Scale; as when three or more tones, of the same scale, are viewed together (three shades of red for example). Secondly, of Tone; as when two or more tones, of the same depth, but belonging to related hues (orange and yellow), are viewed together. Thirdly, of a Dominant Hue; as when the different colours seen are modified in the same direction, as when we view them through a stained glass. (II). Harmonies of Contrast. First of Scale, as when two remote tones, of the same scale, are viewed together (light and dark blue). Secondly, of Tone; as when two tones of different depths, belonging to related scales, are viewed together (dark green and light marine). Thirdly, of Hue; as when remote hues, assorted in accordance with laws of contrast, are seen simultaneously, (blue and red). This kind of contrast may be further enhanced by differences of tone as well as of colour (light blue and dark red).

It should be borne in mind that Chevreul's use of the word "tone" does not agree with that followed in this book. He produces tones by mixing a colour with white or with black.

But in this book tone denotes luminosity, and change of tone change of luminosity. Change of purity is denoted by tint. (Sects. 69, 198, 203, 236.)

305. *Prof. Church's Scheme*—Prof. Church gives an interesting tabulation of colour changes beginning with an imperceptible gradation of one hue, and ending with a collocation of distant hues.

A. One hue. (1). The continuous passage by imperceptible gradations of the tints, shades, or broken tints, of a single hue from light to dark. (2). The discontinuous passage by small but perceptible steps of the tints, etc., from light to dark. (3). The passage, as in (2), each step being separated from its neighbours by white gray or black (neutral elements).

B. Related hues. (4). Continuous passage by imperceptible gradations of one hue, or of its tones, into another related hue, or its tones. (5). Discontinuous passage by definite steps of one hue, or of its tones, as in (4). (6). Passage, as in (5), the steps being separated by white gray or black.

C. Remote hues. (7). Continuous passage by insensible gradations of one hue into a remote hue. (8). Discontinuous passage by definite steps, as in (7). (9). Passage, as in (8), the steps being separated by neutral elements.

D. (10). The collocation of distant tones. (11). The collocation of distant hues, with or without neutral elements interposing.

It will be seen that the idea of gradation, and of a dominant hue, becomes more and more lost as we follow the arrangement, given above. We start with the small interval, (imperceptible changes of some one hue), and end with strikingly contrasted remote colours.

The value of a neutral separating element has been referred to in Sect. 294.

306. *Examples of Harmony, Foliage, etc.*—In the gradual development of foliage (Sect. 27) we have an example of (4), green passing through yellowish-green and greenish-yellow into yellow. We may regard these colour-changes as due to a dominant green, to which is added a continually increasing quantity of red, until yellow is produced. The series conveys an idea of increasing brightness and warmth.

Again, a series of colours, purple, red-purple, red, orange, and yellow, exemplifies (8), the passage by definite steps of one hue into another remote hue. Here also there is common to the whole series the colour red, mixed first with blue, and then with green, and there is a reduction of brightness, as we go from yellow to purple.

Modifications can be introduced by altering the spaces occupied by the different hues, by separating them by neutral elements, or by adding to them white or gray.

307. *Interchange and Counterchange.*—Two series of tones may be interchanged, one set, in ascending order from dark to light, being sandwiched between another set, in descending order from light to dark. A tree, for example, may have the deep tones of its lower branches relieved against a low pale sky, whilst the high tones of its upper foliage may be opposed to the deep tones of the upper sky.

In decorative art the colour pattern and the ground pattern are sometimes ingeniously counterchanged.

308. *Flowers and Leaves.*—Flowers and leaves afford wonderful examples of colour harmonies. Prof. Church instances a plant (*Abutilon megapotamicum*) with green leaves, red calyces, yellow petals, and violet stamens. There is here a double contrast, green and red, yellow and violet, the repetition much adding to the effect. The English violet shows an orange centre, violet petals, and green leaves, a triad of great beauty.

The under surface of many leaves is gray, a gray slightly tinged with green, so that, when reversed by the wind, such leaves afford a beautiful contrast with the richer colour of the unturned leaves. Tennyson speaks of "Blasts which blow the poplar white." The leaf of the Service tree is grayish green on both surfaces, and such a tree is very effective amongst those whose leaves are of a darker green. The evergreen Eucalyptus of Australia has leaves of a sombre bluish green hue.

The autumn tints of leaves supply charming examples of colour harmony, green, red, scarlet, russet-brown, etc. Prof. Church mentions an old beech tree seen in early spring as affording a triple association of hues. The soft gray of the bark, and the olive-green and russet-brown of the moss-patches, present no violent contrasts, but are full of minute variations of texture quality and tone. (Sect. 106.) In Canada and some parts of the United States the change of colour in the fall of the year is startlingly sudden; the maple especially becoming a brilliant scarlet.

> "Unloved that beech will gather brown,
> This maple burn itself away."

> "And Autumn laying here and there
> A fiery finger on the leaves."

> "The flying gold of the ruined woodland drove through the air."

seem appropriate quotations in connection with Autumn tints.

In arranging plants in a garden the general principles of colour-harmony should be borne in mind.

309. *The Landscape, and Local Colour.*—The landscape furnishes admirable examples of colour harmonies. In the foreground, near objects exhibit an extensive range of scale both of tone and hue, and in most cases the warm colours predominate. In the middle distance, the range of tones and hues is shortened. In the far distance the range is very limited, the colours being usually cold and retiring.

Local colour (that is the true colour of an object seen near at hand free from disturbing influences) is, in the distant landscape, of quite subordinate importance. The accomplished artist recognizes this, and, by using various grays, imparts to his pictures a high degree of aërial perspective and luminosity. He well understands the value of temperance in colour, and does not paint a distant field green, when it is really gray. So also a series of similar trees at different distances will be differently affected by aërial perspective, and must not be painted alike. The part of a tree in shadow may be really gray,

but as the part in the light is green, ordinary observers often consider the darker part to be a darker green, thus allowing memory and judgment to warp the actual sensation. (Sect. 54.) Black is scarcely ever seen in landscape, but instead of it, we find a very dark shade of some positive colour, as blue, purple, green, etc.

The influence of a dominant hue is grandly exemplified in the warm flood of red and yellow light poured over the landscape by the setting sun. We have a double harmony, one in heaven, the other, antiphonal to it, on earth. (Sects. 115. 320.)

310. *Supposed analogy between Colour and Music.*—The difference of hue between the colours of the spectrum being associated with a difference in wave-length, and the difference of pitch between the notes of the scale also being connected with a difference in wave-length, there is an analogy—but a very slight one indeed—between colour and music. Our perception of colour does not extend over an octave, if we may apply that term to the interval between two light waves one twice as long as the other. (Sect. 5.) The range of musical sounds is about seven octaves. Attempts have been made to compare the successive notes of the gamut with the successive hues of the spectrum, but the comparison is forced and unnatural. In the musical scale there is progression *per saltum*, in the spectrum there is gradual transition. An interval of a "fifth" can be calculated for wave-lengths of light, but is meaningless to the eye. (Sect. 253.)

Again, when two sounds mingle, we have concord or discord, and can, in the compound tone, distinguish the components; but, when the colours mingle, we have a new colour, in which the components cannot really be separately discerned. For the different pairs of complementary colours, the "interval" is as 5 to 7 in some cases, and as 3 to 4 in others; this again is against any real analogy. The eye is more appreciative of differences of wave length in the middle of the spectrum than at either end (Sects. 9 and 127)

but there is no corresponding peculiarity of the ear. In truth, colour-sensations involve space, sound-sensations time, and the supposed analogies are based rather upon fancy than upon fact.

310A. *Further Remarks.*—Mr Haweis, in his eloquent work—"Music and Morals"—speculates upon the possibility of inventing an art which shall stand to colour in the same relation as music stands to sound. In a sunset, he says, we have the musical qualities of elation, depression, velocity, intensity, variety, and form, represented by the passage of dark tints into bright ones, by palpitations of light and mobility of hues, by poorness or richness of the same colour, by the presence of varied hues, by the areas occupied by different colours.

But with the musician sound is essential, not accessory, to the emotions it excites; with the painter colour is merely accessory. No method he says has yet been discovered of arranging colour by itself for the eye, as the musician's art arranges sound for the ear. But Mr. Haweis believes it to be possible to so display colour effects as to give, through the eye, emotions comparable with those excited, through the ear, by grand musical symphonies. He speaks of orchestral blazes of incomparable hues; of delicate melodies, composed of single floating lights, changing and melting from one slow intensity to another through the dark, until the tender dawn of opal might receive the last fluttering pulse of ruby flame, and prepare the eye for some new passage of exquisite colour!

It seems to me quite possible that in painting, as in music, the occasional introduction of inharmonious combinations may increase the effect of the harmony itself; and I cannot but believe that, seen by the artistic eye, the colours of Nature, infinite in variety, inexhaustible in tenderness and richness, do produce a delight comparable with, perhaps not inferior to, the charm which the musician receives from a symphony of Beethoven.

PART XVI.—PAINTING AND DECORATIVE ART.

311. *Diverse Aims of Painting and Decorative Art.*—The aim of Painting is the production by means of colours of representations, as perfect as possible, of natural objects. The aim of Decorative Art is to beautify a surface by the use of colour. It is true that the Painter cannot exactly represent Nature, but he tries to do so in a serious spirit, and when he is obliged to be exclusive, or conventional, it is because he cannot, with finite means, represent the infinite. He includes what is essential for his purpose, excluding what is accidental. His pigments are such poor representatives of the luminosity of the brighter natural colours (Sect. 315), that he cannot do what he would. On the other hand, the pale unsaturated colours of distant landscape (Sect. 309), are liable to be represented by pigments too rich and intense, unless much care is exercised.

Painting appeals to the mental as well as to the physical eye. An attempt is made to lead the observer's mind *under* the surface to the realities intended to be expressed.

In decorative art, rich and intense colours are often selected, and their effect is heightened by the free use of gold and silver, or white and black. All that is meant to be seen is on the surface. The ornamental exterior is itself the beautiful object. But, in a picture, we feel we have simply a representation of a beauty, which is really absent. Much greater freedom is permissible in decorative art than in painting. Tragedy, mystery, and sorrow, are all legitimate aims for the painter, but the decorative artist aims at giving nothing but pleasure.

In painting large use is made of the all-important principle of gradation in colour and in light and shade; and the colours used are often pale and subdued. Tracery, patterns, sharp outlines, etc, are characteristic of decorative art, gradation being of minor importance.

In pictorial art colour is the means, in decorative art it is the end. In the former colour is subordinate to form, in the latter form is subordinate to colour.

312. *Monochromy and Polychromy.*—Monochromy is decoration in a single colour. In order to avoid monotony the small interval is employed, and this, to a certain extent, links together painting and monochromy; but in the latter there will be definite outlines, separation by neutral elements, and repetition; all of which differentiate monochromy from painting truly so called.

Polychromy is decoration by means of a number of distinct colours, (with or without outlines in gold, silver, white, and black), employed simultaneously. The intenser colours cover the smaller areas, the paler ones the larger. A broad general effect is produced by the repetition of a few simple elements. The Moorish Alhambra is a superb example of decorative art. The main colours are red, blue, and gold, and narrow white lines separate adjacent hues. Sometimes the colours are interwoven so as to blend at a distance. (Sects. 106, 299.)

It is a mistaken view of decorative art to endeavour to cover carpets, papers, shawls, etc., with groups of flowers, figures, and landscapes, executed in a style which properly belongs to the painter of nature. Intentional realism of this kind cannot for a moment deceive us, and we feel that the decorator has usurped and misapplied the function of the painter.

An interesting paper (by Mr. Carter), on the decoration of a modern house will be found in the 1887 volume of the Transactions of the Cardiff Naturalists' Society. Mr. Carter thinks it possible that we may in time hope to rival the Greeks.

313. *Stained glass, porcelain, gems.*—Prof. Church has some valuable remarks upon the use of stained glass. [The glass must not pretend to be a picture, nor must it contain large portions nearly opaque to light. Minute details are quite out of place. Where the windows are large, a very rich effect is produced by making blue preponderate. Ruby-red with blue and golden-yellow yields a delightful harmony.]

The luminosity of stained glass far transcends that of pigments. (Sect. 16.) Perfectly clear uniformly coloured glass, such as is seen too often in conservatories and hall-windows, does not give a pleasing effect. It is crude and wants variety. There is none of the subtle gradation and play of nature. A better result is got by varying the thickness of the glass, or by diffusing the colouring matter in it irregularly.

With earthenware and porcelain, the peculiar effects of colouring and painting will depend, partly on the transparency or opacity of the pigments, and partly also upon translucency or opacity of the ware. The glaze also influences the result.

In arranging precious stones, attention should be given to their form, lustre, light, and colour. (Sect. 282.) For details on this subject reference may be made to Professor Church's books. But it is obvious that contrast in colour and in light may be aided by contrast in form and in lustre. (Sect. 38.) Waxy and adamantine lustre, plane and curved forms, may be associated, and so for other cases.

The right employment of the different ornamental minerals, such as lapis-lazuli, agate, malachite; and of tiles, tesseræ, marbles, alabaster, porphyry, granite, building stones, etc., involves a consideration of their colour, texture, polish, translucency, lustre, etc. (Sect. 282.)

The practical application of the principles of colour to the different branches of decorative art is an immense subject, which cannot be more than indicated in a book such as this. Tapestry, carpets, furniture, mosaics, stained windows, colour-

printing, calico-printing, wall-papers, architectural work, interior decoration of various buildings, clothing, horticulture, are some of the subjects to which the principles of colour will apply. It is unfortunate that Chevreul in his treatment of the foregoing follows the red-yellow-blue theory of primaries.

313A. *Minerals.*—Minerals exhibit a great variety of colour, apart from such properties as lustre, iridescence, pleiochroism, etc. The streak or coloured line, produced, either by scratching the mineral, or by rubbing it on a rough white surface, gives, in many cases, the colour of the substance in powder. Among *black* minerals are graphite, magnetite, pyrolusite. *Yellow* minerals include sulphur, gold, pyrites, orpiment, crocidolite (orange), amber, topaz, mimetite. Pyromorphite is greenish-yellow. *Red* minerals include copper, realgar, cinnabar, minium, hematite, garnet, ruby. Rhodonite is pink. *Green* and *marine* minerals include malachite, turquoise, chrysocolla, emerald, nephrite, chlorite. Olivine is dark yellowish green. Among the *blue* ones are found lapis-lazuli, chessylite, sapphire. Lepidolite is pale *purple.* Baryte, gypsum, calcite, dolomite, rock salt, may be *white* or transparent, and are sometimes coloured by impurities. Hornblende, felspar, mica, tourmaline, serpentine, quartz, fluor spar, are found variously coloured. Some of the varieties of quartz are named from their tints, smoky, rose, carnelian, chrysoprase, sard, blood.

313B. *Rocks.*—Rocks are perhaps as variously coloured as minerals, but usually the colours are duller. As a rule the basis of the colouring matter is iron, and the commoner colours are reds browns and grays. Granites are generally white or red. Sandstones are usually red, yellow, brown, or white. Slates may be purple, gray, green, blue, etc. Clays are very various. Limestone may be white, gray, blue, red, black, etc. Dolomite limestones are often of a beautiful creamy tint. Marbles are simply compact limestones, which will take a high polish. They are frequently veined or

mottled. The decomposition or weathering of a rock generally changes its colour, and the effect is specially noticeable in igneous rocks. The sinter, or geyserite, in the Yellowstone Park, may be found vividly coloured, cream, salmon, crimson, red, brown, yellow, etc. Nearer home, the sands of Alum Bay, and the serpentine of the Lizard, afford beautiful examples of rock-colouring. (See also Sect. 313C.)

The following quotation is from a paper about the Yellowstone National Park, and refers to rock-colour.

[There are few sights in the world so wondrous and so weird as the Grand Cañon of the Yellowstone. Turner, the world's greatest landscape painter, when at the height of his genius, might have rendered some justice to a scene which Nature has steeped in a wreath and variety of colour elsewhere unsurpassed. . . . The yellow, deep red, and other tints, are doubtless due to the action of hot springs, the weathering of the rock, the presence of sulphur, and the oxidation of iron, which here—as elsewhere—is Nature's principal pigment. . . . Up the pine-fringed gorge we look to the Great Falls, and down we gaze along a still deeper cañon with black basaltic walls, between which runs the river—a ribbon of emerald.

Like some of the Tyrolean Dolomites, one pinnacle stands drenched crimson as with the blood of sacrifice, whilst near it rises a cliff white as the chalk of Dover. "The whole gorge flames. It is as though rainbows had fallen out of the sky and hung themselves as glorious banners. The underlying colour is the clearest yellow, this flushes onward into orange. Down at the base the deepest mosses unroll their draperies of the most vivid green; browns sweet and soft blend together. It is a wilderness of colour. It is as though the most glorious sunset you ever saw had been caught and held upon that resplendent awful gorge." Marvellous effects are produced by the morning and evening light. One painter there was actually adjusting the colours of his pigments by matching them with pieces of the tinted rocks.]

In representing rocks, a little knowledge of geology will be of essential service. The texture of the stone itself, its structural arrangement in the mass, and its manner of weathering, should all be studied. Too often the treatment of rocks is utterly conventional. How greatly a granite foreground differs from one of limestone, and this again from one of terraced trap. Nay, we may go further, and say that every boulder has its individual peculiarities; and that, just as no painter would think of putting oak leaves on a birch tree, so no painter should represent one rock with the character of a quite different one. (Sect. 327.)

(See Prof. Geikie's admirable remarks in his "Scenery and Geology of Scotland.")

313C. *Woods, Flowers, Animals.*—*Woods* offer a great variety of shades of brown, etc, but their main differences of appearance are due to variations in texture and lustre, and to the pecularities brought out by polishing. All these matters are to be considered in ornamental woodwork. A dark lustrous wood looks well with an opaque light coloured one, and so on. (Sect. 39.)

Flowers exhibit a wonderful variety and richness of colour. Probably no colour is unrepresented in the vegetable world. Lichens often attach themselves to rocks, and the colour seen is then that of lichen not of rock. (Sect. 313B.) Lichens are very various in hue, some are a brilliant scarlet, others orange, etc.

[On the Darwinian hypothesis it seems very probable that all flowers were originally green and inconspicuous, as are those of so many plants still. Further, it seems not unlikely that in order of development white yellow and red flowers preceded blue. In the Ranunculaceæ, the simple open flowers are generally yellow or white, but the larkspur columbine and aconite (which are highly specialised and therefore probably more recent forms) are blue. In the Primulaceæ, the open-flowered honeyless species are generally white or yellow, while red blue and purple occur chiefly in

the highly specialised species. Among the violets, some are yellow, some blue. Müller considers yellow to be the original colour. A small comparatively little specialised violet (*V. biflora)* is yellow, while the large long-spurred violet (*V. calcarata*), specially adapted for humble-bees, is blue. The *Myosotis versicolor* is first yellow then blue, the individual flower repeating the ancestral colour-changes. In Gentians the species with long tubular flowers (adapted for bees and butterflies) are deep blue, while the yellow gentian has a simple open flower with exposed honey.

It has also been pointed out that the blue flowers, (which, according to this view, are descended from white or yellow ancestors, passing in many cases through a red stage), frequently vary, (as if the colours had not had time to fix themselves), and by atavism resume their original colour. Many normally blue flowers are often reddish or white. On the other hand, flowers normally white or yellow, rarely, or never, vary to blue. Although there are comparatively few blue flowers, still, if we consider the specialised honey-concealing flowers, we shall find that the percentage of them that is blue is greater than it is among unspecialised flowers. Sir J. Lubbock.]

The subject of colour in the *animal* world is extensive enough to need a treatise to itself. The remarkable changes exhibited by the Chameleon are proverbial. The various tints assumed seem to be due to the change of position of small coloured corpuscles in relation to the coloured skin through which their effect is seen. The Octopus possesses a similar power of changing its colour, and the tints assumed appear to vary with those of the ground over which it passes.

Colour is of course a very essential element in protective mimicry, which plays an important part in the great struggle for existence. We find leaf-eating insects green, bark-feeders mottled-gray. The Alpine ptarmigan is white in winter; the red grouse resembles the heather; and so on. The brilliant colours, so often displayed by male birds, are attributed by Darwin to sexual selection. In the animal

world, variety brilliancy and play of colour would appear to culminate in those living jewels—the humming birds. (Sects. 44, 63A.)

From a very numerous series of experiments Sir John Lubbock thinks that: (1), ants can distinguish colours; (2), that they are very sensitive to violet; (3), that their colour sensations must be very different from ours; (4), that their limit of vision at the red end of the spectrum agrees with ours, but that they perceive and are very sensitive to the (to us) invisible ultra-violet rays. He is also of opinion that bees and wasps can distinguish colours, and that bees show a preference for blue.

314. *Progress of the Artist, etc.*—It appears to be a good plan for the painter to begin by executing pictures in monochrome (as sepia), which however is constantly varied in shade and tint. Then he adds to his palette another hue, say a bluish colour. Gradually, as progress is made, a greater number of colours may be employed, and true pictures produced. Many artists produce impressive effects by modifying the colours, so as to appear as if under the influence of some dominant light. (Sects. 309, 320.) If colours are slightly altered from the natural ones, but still are *relatively* correct, the effect will still be good. (Sects. 117, 318.)

Rapid colour-sketching of the same scene, under varying degrees of illumination, is a most valuable aid to the artist. Such sketches may be accompanied by notes of any very transient effects. In such sketching, high finish need not be aimed at, but rather broad general effect, the tints being painted in at once as correctly as possible.

Powerful drawing adds greatly to the effect of a picture in which the tints are delicate or pale, as is so often the case in nature. By good gradation we can overcome the difficulties presented by poor or weak colour combinations. It is hardly necessary to speak of the importance of using clear pigments.

Reference has been made (Sect. 309.) to the fact that, though a distant field may appear green, its actual colour may be practically gray just tinged with green, and this may often be rendered evident by isolating the colour by viewing it through a small aperture. The colours of objects are also affected by their surroundings, as was explained when contrast was treated of. The tone and tint and hue may all be affected by the environment. (Part. X.)

It has before been stated that it is not easy to make successful pictures of objects in which green largely predominates. (Sect. 272.)

For the immense value of gradation in pictorial art, see Sect. 297.

315. *Luminosity in Nature and in Paintings.*—In the matter of luminosity Nature infinitely transcends the pigments of the artist. (Sect. 193.) The sky is not blue colour merely, it is blue fire, and therefore cannot really be painted. We have nothing brighter than dense white paper, or white lead, nothing blacker than lamp black, and we must represent nature, many of whose *shadows* are brighter than our white paper, with materials so inadequate as these.

The artist must therefore fail somewhere, the question being:—At which part of the scale will he be false? According to Ruskin, Rembrandt is false at the lower part of the scale, where all is lost in blackness. Many of Rembrandt's pictures are wonderful examples of the effect of a dominant coloured light. (Sect. 115.)

Veronese is false at the upper part of the scale, where all is lost in whiteness. Turner is weakest in the middle tints, generally between the earth and sky. Ruskin draws the conclusion that Turner comes nearer than any other to the true representation of the colours of Nature. The reader may be referred to "Modern Painters"; Part II. Sect. II., and to Part V. Chap. III.

316. *Helmholtz on Light and Shade.*—Prof. Helmholtz has some very instructive remarks upon the representation by the Artist of the light and shade of Nature.

If the artist is exactly to imitate Nature he ought to be able to have at his command brightness and darkness equal to those in nature. But of course he has nothing of the kind. Compare a painting of a desert scene, in full sunshine, with one of a moonlit landscape. (Sect. 201.) Both can well recall the realities, but in both the brightest parts are produced by the *same* white paint, the darkest with the *same* black paint; and yet the sun is about 800,000 times brighter than the full moon. The brightest white of a picture is probably less than one twentieth of the brightness of white placed directly in sunshine, so in the picture of the desert scene the white is twenty times less bright than it is in the reality; and such a white, placed by the actual object, would be gray. On the other hand, in the moonlit picture, the white parts will be 10 to 20 times brighter than the real objects. The darkest black paint is not dark enough, under daylight, to represent the feeble illumination of a white surface under moonlight. Why then do the pictures seem similar to the realities?

317. *Condition of the Eye.*—First, it must be remembered that an observer in the desert would have his eye fatigued (Sect. 235), and deadened by the glare, whilst in the moonlight the sensitiveness of the eye would be at a maximum. So the painter has to produce upon an eye, in an ordinary normal state, the same impression that the desert-scene produces on the fatigued, and the moonlit-scene on the over-sensitive, eye of its observer. Physiological conditions become of great importance. The painter has to give, not a mere transcript of the object, but a *translation* of his impression into another scale of sensitiveness, in which the eye is in a different condition.

318. *Fechner's Law.*—The principle which will be found to solve the difficulties, we have named, is known as Fechner's Law:—Differences in the strength of light are equally distinct to our senses, if they form an equal fraction of the total quantity of light. If the minimum of difference re-

cognisable be one hundredth of the total, we recognise such a difference (within wide limits), whether it occur in a bright or a weak light. If a white and a gray piece of paper be placed side by side, they will continue to appear relatively white and gray under very different degrees of total illumination. So the painter endeavours to give to his colours the same *ratio* of brightness as that which actually exists. The total illumination of the picture may exceed or fall short of that of the reality, but the similarity is preserved if the *ratio* of the brightness of the parts to that of the whole is the same in each. (Sects. 117, 314.)

319. *Its Limits.*—But Fechner's law holds only within reasonable limits. At both extremes of brightness and darkness the eye is less sensitive for differences than is required by the law. We cannot appreciate a difference of one hundredth part in a very bright or a very feeble illumination. (Sect. 199.) So, in glowing sunshine, bright objects are nearer the brightest, and, in dim sunshine, dark objects are nearer the darkest, than is the case within reasonable limits of illumination. The painter, to represent a bright sunlit scene, paints the objects almost equally bright; but, in representing a moonlit scene, he keeps everything, except the very brightest objects, so dark as to be almost unrecognisable. In both pictures he expresses by this gradation the insensitiveness of the eye for differences of very bright or very feeble lights; and so overcomes the difficulty due to the fact that both pictures will have to be viewed in the same moderately lighted room.

For the artist the great point is to imitate, not absolute brightness—that is beyond his power—but differences of brightness.

320. *Devices of the Artist.*—In representing sunlit scenes the artist also takes advantage of the fact that highly luminous white tends to yellow, and he adds a little yellow to his highest light; while, as dull white tends to blue, he adds a little blue to bring out the fact. (Sect. 195.) (It

was mentioned before (Sect. 27) that a yellow glass makes a landscape look sunny, a blue one wintry.) These devices of the artist would be unnecessary if he had at his command pigments truly representing the luminosity of natural objects. The subjective action can only be represented objectively by actually altering the ordinary pigments, which, being only moderately bright, cannot otherwise produce the effect of the real objects.

The character of the composition will evidently vary with that of the dominant light (Sects. 115, 309), and, when this is yellow, blues and violets will be weakened, greens will become yellowish, and red yellow and orange will gain in strength. Just the reverse will be the case for a bluish dominant illumination. As a rule pictures, in which the warmer tints preponderate, are more pleasant than those in which the opposite obtains. (Part XIII.)

321. *Effect of Contrast, and of Irradiation, imitated.*—Again in the matter of *contrast* (Part X.) the artist works at a disadvantage. If his colours were as brilliant as the actual objects, the contrasts in the picture would equal those in the real things. But as the pigments in many cases are not bright enough of themselves to give sufficient contrast effect, the painter may aid the contrast effect by painting it in to some extent, thus producing objectively what there is not brilliance enough to produce subjectively (Sect. 235). A gray surface may be painted lighter where it approaches a dark object, and darker where it is near a light object. So too a gray surface may be tinted yellow near a blue background, and rosy-red near a green one; and sun-rays, coming through chinks in an orange blind, may be tinted greenish blue. (Sect. 211, 224.)

The phenomena of *irradiation* (Sect. 233), which occur only in connection with very bright lights, must be represented in a painting objectively, because the brightness of the painting will not of itself produce the phenomena.

322. *The Painter's Aim.*—So we see that the painter does his best to reproduce, not necessarily the actual colours, but the impression they give. He has to change the scale of luminosity or colour, but retains as far as possible *gradations* corresponding to the natural ones. Subjective phenomena, which his pigments may not fully produce, he aids by objective representation. In availing himself of the resources of his art, individuality will come into play, and hence the different style and treatment seen in such men as Rembrandt and Turner.

The Artist will not necessarily merely reproduce, as nearly as he can, what he sees; but he will, when he thinks fit, idealise and refine, adding to his picture elements of beauty which he has gathered from prolonged experience. Through the material picture should be visible the creative mind of its painter. (Sect. 311.)

As examples of paintings, whose colours are almost "unearthly" in their ethereal loveliness, perhaps I may instance some of those from the brush of Sir Frederick Leighton, P.R.A.

There is an interesting anecdote of Sir Joshua Reynolds, which well shows how, what some might consider a comparatively unimportant part of a picture, really calls for true artistic skill. A friend wished to apprentice his son to Sir Joshua, who naturally asked what the lad could do. "He might put in your backgrounds," said his father. "If he can do that," replied the Artist, "I have nothing more to teach him."

323. *Advantages of moderate illumination, etc.*—Would it really be an advantage to paint pictures so that they should be viewed in direct sunlight; or is painted glass superior to an ordinary picture? The works of great painters, executed in comparatively dull colours, appear to answer these queries in the negative. Moderation, or temperance, in light and colour is always advantageous. The eye is too much fatigued by very bright pictures. As Helmholtz says: The

true picture reproduces all that is essential and attains full vividness of conception, without tiring the eye by the nude lights of reality. The discrimination of fine shades of colour is most delicate under a *mean* illumination. (Sect. 199.)

If the surfaces coated by a prominent colour are too large, fatigue of the retina is produced, accompanied by diminished sensitiveness. As was mentioned in Sect. 285, certain complementary colours can be used with good effect, and so also may colours, which are separated by only the small interval. (Sect. 293.) Then again, triads of colour are pleasing, when so balanced as to prevent any one-sided fatigue of the retina by undue preponderance. (Sect. 289.) Orange, green, and violet, or purple, marine, and yellow, form good combinations. Often too we must make one colour predominate as a dominant hue.

324. *Binocular vision and perspective, etc.*—The depth of solid objects can of course only be imitated, not actually realized, in a picture painted on a flat surface. So great care must be taken in the matter of light and shade and perspective to minimise this defect. The true artist, like the true poet, idealises, but so as to bring us nearer to the deep-lying realities.

A good deal of this Section and of the two next Sections is based upon Helmholtz's Lectures.

By a proper perspective drawing we can present to an observer, supposed to look with only one eye, a correct image of an object. But we see objects usually with two eyes, each eye presenting to us a view slightly different from that of the other, and it is well known that this binocular perspective forms one of the most important means we possess for estimating depth and distance. It is of course impossible for a *picture* to give different images to the two eyes, so that in this respect the painter is at a great disadvantage. It is only by painting two slightly different views of the same objects, and then stereoscopically combining these views that this difficulty can really be overcome.

The very fact that a picture is the *same* to both eyes forces us to see that it does not present depth, but only a flat surface. This peculiarity is the more striking the smaller and nearer the picture is. A large picture at a distance is more realistic than a small one close at hand, for the effect of binocular perspective diminishes with distance. A picture, near at hand, will gain in reality by being viewed with one eye only.

324A. *Parallax.*—But, even when we look with a single eye, we shall find that if we shift our position, real objects suffer parallax or relative displacement. Fix the eye on any given object, and then walk at right angles to the visual line. We notice that the more distant objects appear to move with us, the nearer ones to move in the opposite direction. Also, if we directly approach or recede from an object, any pair of objects, nearer to us than the one looked at, and situated so as to be seen one on its right the other on its left, will appear to open out from, or to close upon, the central object.

These parallactic effects are necessarily absent from pictures, and one result of this is that the eyes of a portrait appear to follow the spectator about the room. The marvel would be if they did not do so. For distant objects, *inter se*, the parallax is less than for those near at hand, hence another reason why a large distant picture is to a shifting spectator more real than a small one at hand.

324 B. *Projection, shadows, aërial perspective.*—The difficulties named cannot be overcome, but they can be lessened. Nearer objects may partially conceal more distant ones, but can never themselves be hidden by the latter. This fact will enable us to suggest depth.

Again, bodies of regular shape or known form have a projection-form characteristic of them, and this form will suggest the whole shape of the body, as for example in the case of a building, or of a bilaterally symmetrical object. But for irregular bodies, such as foliage and rough blocks

of rock and ice, perspective projection is of little avail, a fact well brought out by looking at a photograph of a glacier. But, combine by the stereoscope two slightly dissimilar views of the same glacier, all confusion vanishes, and the picture stands out with all the reality of a solid object.

The apparent magnitude of known objects is a very useful item, and by comparing the sizes of the representations of two similar objects, one in the foreground the other in the background, we get an idea of the distance between them.

Shadows are of great value for suggesting reality. Only by delicate gradations of light and shade can the moulding of rounded surfaces be imitated. Shadows will vary with the position of the light throwing them, and in certain circumstances, will not be visible, and then the relief they give is wanting. Lateral lighting is the best for giving shadows, and if the surfaces are flat, the light should be low. Hence the illumination from a rising or setting sun is very effective. The smaller the light the sharper the shadows; but if the light-giving body is large—as a cloudy sky for example—the shadows are diffuse and faint.

But for giving the idea of distance, perhaps the most important of all aids is that afforded by aërial perspective. The artist paints into his picture the effect produced by the optical action of the illuminated masses of air, which intervene between the observer and distant objects. The subject has been fully discussed. (Sects. 54—60A, and 309.)

One of the great charms of water-colour painting lies in the delicacy beauty and truthfulness with which it can be made to represent aërial effects. (Sect. 266A.) The colour is often aided by the texture of the paper, the little hollows and projections producing half-lights and lights. It is distance and depth, not surface, that the sky-painter must represent, and no uniform layer of colour will do this. Clouds are of course greatly influenced by aërial perspective, and to correctly depict them is far from easy. (Sect. 327.) The tints used should be thin and flowing into one another,

so that transparency and gradation may be secured. When atmospheric effect is wanting to a picture, the cause will often be found to be the absence of bluish-grays.

As a very beatiful example of the bluish effect of distance upon landscape colours, I may perhaps instance Vicat Cole's grand picture, "Noon on the Surrey Hills" (Cardiff Museum). An artist friend tells me that, to a delicate eye, the interposition of only a few yards of atmosphere will perceptibly modify colours seen through it.

324c. *Prof. Le Conte on Perspective.*—The following concise summary is taken nearly verbatim from a book by Professor Le Conte of the University of California.

[The painter can imitate aërial perspective, by diminishing the brightness, dulling the sharpness of outline, and adding a blue tinge, so as to produce the effect of supposed distance and depth of atmosphere. He can still more perfectly imitate mathematical perspective by diminishing the size of objects, and the distance between them, as he passes from foreground to background. Focal perspective he cannot imitate, but this is of small importance, because imperceptible at the distance at which pictures are usually viewed. Binocular perspective he cannot imitate; it is artificially obtainable only by combining, as is done by the stereoscope, two slightly dissimilar pictures. The want of binocular perspective in paintings interferes seriously with the completeness of the illusion. Therefore the illusion is more complete, and the perspective comes out more distinctly, when we look with only one eye. In a natural scene it is exactly the opposite: the perspective is far more perfect with both eyes open, because then all forms coöperate.]

325. *Danger of seeing too much.*—Not only must the artist guard against seeing too little, there is the danger also of seeing too much. If he is painting a bit of shadow in a sunlit landscape, the correct way to represent it would be without much attention to detail, for details in shadow would

be not observable in a general glance at such a landscape. But, if the artist concentrates his attention on the shadow, he may discern details, and may be tempted to put them in his picture. Artistically this would be a mistake, for what we want is the effect of the landscape as a whole. Similar remarks apply to a very bright patch in a duller back ground. The painter's tendency, as he paints each separate part, is to exaggerate the local differences of light and shade, to over-accentuate local details at the expense of the general effect; this tendency, being due, not to an error of judgment, but to the actual physiological peculiarity of the eye. The painter sees these things, but must carefully learn not to paint them.

If the illumination of the picture were the same as that of the landscape these difficulties would not arise, and the details, if painted, would not be noticed, in the general view of the picture, any more than in the landscape itself. It will be remembered (Sect. 320) that the colours of pictures lose in warmth by a diminished illumination, and this is one of the many difficulties that beset the artist, who must adjust his tones accordingly.

In painting such an object as a tree we have to give the joint effect of multiplicity and mass, and it is very easy to lose the general effect by too great attention to detail.

[Painting does not consist in the mindless copying in mosaic of all you can see in Nature scrap by scrap. It consists in the thoughtful and direct conveyance of a single fresh impression, unincumbered by matter not to the point. —*Duran.*]

326. *Technical and Artistic sides of painting.*—Sir John Collier well says:—[There are two sides to painting, the one is strictly technical and demands good workmanship and intelligent observation. The other may be called the artistic side, and demands good taste, or feeling for beauty, and, in its highest aspects, poetry and imagination].

There is no reason for the slightest antagonism between the two; as a matter of fact they should be mutually helpful. Yet, I fear, it is too often true that the artist has something like a contempt for physical science, and believes he has nothing to learn from her. But not only would a little knowledge of the scientific basis of his work save him much time by indicating the proper means for achieving results, it would also save him from perpetuating the serious errors patent in many pictures. (Sect. 327.)

327. *Errors made from ignorance of Science. The Rainbow, etc.*—It may be useful to point out some of the errors into which painters may be led by ignorance of science.

Rainbows have been, and still are, sometimes painted inside out as to their colours. The angular magnitude and width of the bow, and its position relatively to the sun, are by no means always correctly given.

The ordinary Primary Rainbow is produced by sunlight, which, having been incident on raindrops, emerges after two refractions and one reflection. During the refractions the light is dispersed, the waves of different lengths being separated, hence the colours seen. The centre of the bow is opposite to the sun, so that the height of the bow above the horizon varies inversely with the sun's altitude, and is at a maximum (the bow being then a semicircular ring) when the sun is on the horizon. If the sun's altitude exceeds 42° no rainbow is visible from the sea-level. As we rise above the sea-level more and more of the bow comes into sight, and from a mountain top the circle may be seen complete.

The mean angular magnitude of the radius of the bow is about 41°, and its breadth is about 2⅓°, or nearly four and a half times that of the sun. The outermost ring of the bow is red, fairly pure. Within this red ring will be seen a series of coloured rings, somewhat mixed, but gradually varying, in spectral order, from red to violet. Inside the violet will be a space of sky brighter than the average, whilst outside the red margin the sky will be comparatively dark.

The sun, not being a point of light, all colours, except the outer red and outer violet, will be rendered more or less impure. In addition to this the presence of light, refracted at angles, other than those of minimum deviation, will modify all colours except the outer red.

When the sun shines brightly there will be seen outside, but concentric with, the primary bow, a faint Secondary Rainbow, produced by rays which have been twice reflected and twice refracted by the drops. Between the bows is the dark space already referred to. The mean angular magnitude of the radius of the secondary bow is about 52°, and its breadth is 3½°, or nearly seven times that of the sun. The innermost ring of the bow is red. Outside this red will be seen a series of coloured rings, faint and impure, but varying in spectral order from red to violet. Beyond the violet the light gradually fades away. If the sun is low the more refrangible colours of the bows will be relatively weakened, and may even be invisible.

In a lunar rainbow, owing to the feeble light of even the full moon, scarcely any variation of hue is discernible. (Sect. 201). Fogbows are generally white. The coloured bows seen near waterfalls, fountains, geysers in eruption, etc., are merely miniature copies of the rainbow; this phenomenon of colour dispersion by water is presented in its simplest, but not least beautiful, form, by the dewdrops which sparkle in the morning sun like luminous jewels, emerald, sapphire, ruby.

Clouds are sometimes painted bluer than the sky, but the sky is our "blue cloud" and cannot well be painted bluer than itself. (Sect. 56.) Occasionally clouds are painted green—an impossible colour for a cloud. (Sect. 57.) The colours displayed by the borders of thin clouds, and those of coronas seen on thin clouds (which come between the sun or moon and the observer) include all the spectral hues. They are produced by interference (Sect. 62) and do not constitute any real exception to what is said about cloud-colour.

Skies and clouds are far more difficult to represent in oils than in the more delicate and transparent water-colours. (Sect. 324B.) The form and texture of clouds, such as the lofty feathery cirrus, the low sheet-like stratus, the wool-pack cumulus, springing from a horizontal base (the plane separating the condensed from the uncondensed vapour of an ascending air-column), and their combinations, are all characteristic, and require to be as carefully studied and discriminated as ordinary terrestrial objects.

The laws of perspective also apply to clouds. Of a thin flat broken sheet of cloud at a great height, the portion directly above us will show simply its flat under surface, but, as we lower our glance, the thin edges of the flakes will appear more and more like bars, thinning as they approach the horizon, and thus instinctively conveying the idea of distance. *(Abercromby.)*

Clouds are composed, not of vapour properly so called, for this is invisible, but of minute droplets of water. But clouds at a very high level are composed of spiculæ of ice, for at a great elevation the temperature is such that water would be frozen, and the phenomena of halos, mock-suns, etc., found only in connection with very lofty clouds, cannot be explained except by the action of prisms of ice. So much is now known of the intimate interdependence of clouds wind and weather, that no landscape artist can afford to be ignorant of the modern sience of Meteorology.

The order of the tints seen at sunrise or sunset is occasionally incorrectly represented. (Sects. 56-7.) The crescent moon, in pictures, is frequently placed either wrongly in relation to the sun, so far as position in the sky is concerned, or her horns are turned in some direction other than the right one. Sometimes it is forgotten that the full moon is always opposite to the sun. Stars should be shown, not scattered at random, but grouped in constellations.

The well-known optical law—that the angle of reflection equals and is in the same plane with that of incidence—is not always remembered. From this law it follows that the "wake," seen when light is reflected from furrowed water, must never run across the painting, but always directly towards the eye of the spectator.

Lightning flashes may be studied with the aid of instantaneous photography. The electrical phenomenon known as the Aurora so rarely displays its magnificence in our latitudes that it need not be more than mentioned. For the peculiar effects of irradiation, see Sect. 233.

Painters who have been trained as architects will not be likely to commit any grave mistakes in the matter of perspective, and their technical information will also be of great use when castles, churches, and similar objects, form the subject of the picture.

To draw and paint rocks correctly an artist should know something of geology (Sect. 313B); so also to represent flowers he should be something of a botanist; to represent animals something of a zoologist. Absurd anatomical mistakes are frequently made by those who may be excellent colourists. It seems probable that, in the very difficult matter of representing animals in movement, great help might be obtained from the study of a series of successive instantaneous photographs (Sect. 231), remembering carefully, however, that what the painter has to represent is, not a momentary view, but a generalised effect. But scientific knowledge, though so important, is not the first requisite for the painter of animals, he must be like Landseer a lover of them, or he will never place on his canvas forms which need but the breath of life to make them real.

327A. *Notes on the Turner House.*—The Turner House, recently (June, 1888) opened at Penarth, contains a most interesting and educative series of etchings and prints, and of paintings in water-colour and oil. Mr. Pyke Thompson's

generous boon to the public is made still more valuable by the addition (to the Catalogue) of suggestive notes from the pen of the accomplished Art-critic—Mr. Fred. Wedmore.

Appended are a few observations illustrative of some of the matters treated of in this book. The numbers are the same as those in the catalogue.

No. 5. Black Gang Chine. The geological structure of the rocks, and, in the falling water, the symmetrical series of catenary-like curves, are both admirably shown.

No. 7. Edinburgh. (Turner). An illustration of aërial perspective in the effect of distance given by the sun-lighted haze between the observer and the Castle. "The Bosphorus"—another beautiful example of Turner's marvellous power of representing atmospheric haze—is in the possession of Mr. D. T. Alexander of Dinas Powis.

No. 8. River Scene. In this there is a double rainbow, the secondary one however repeats the colours of the primary in the *same*, not as should be the case, in the *inverse* order. (Sect. 327.) Also, the bow is a semi-circle, so the sun must be just on the horizon, but the dominant light of the picture is not that of a very low sun.

No. 16. Golden Twickenham. Here the sky is represented of the same blue from the horizon upwards. Near the horizon the sky should, I think, be of a grayer hue, and there should be a subtle gradation from this into the deeper blue above.

No. 18. Dryslwyn Castle. In this picture the haze of intervening atmosphere is well depicted.

No. 33. The Lake. The opal light is remarkable, and is of a kind not, I think, often seen under English skies.

No. 110. Fair Rosamund. This picture well illustrates the contrast of red-orange hues with blue-green ones. The colours are nearly complementary, so that the contrast is a forcible one, but it is at the same time a little "hard." (Sect. 284.) (See also Sect. 266.)

328. *Colour a Benediction.*—Prof. Rood says: [Eyes gifted merely with a sense for light and shade would answer quite well for most practical purposes, and would still reveal to us in the material universe an amount of beauty far transcending our capacity for reception. But over and above this we have received yet one more gift, something not quite necessary, a benediction as it were, in our sense for and enjoyment of colour.]

329. *Ruskin on Colour and Chiaro-oscuro.*—But, after all, colour is subordinate to chiaro-oscuro (light and shade), Sect. 209. Ruskin (*Modern Painters*, Part II, Sect. II, Chap. II, § 20), writes:—

[Turner paints in colour, but he thinks in light and shade; and were it necessary, rather than lose one line of his forms, or one ray of his sunshine, would, I apprehend, be content to paint in black and white to the end of his life. It is by mistaking the shadow for the substance, and aiming at the brilliancy and the fire, without perceiving of what deep-studied shade and inimitable form it is at once the result and the illustration, that the host of his imitators sink into deserved disgrace. With him, as with all the greatest painters, and in Turner's more than all, the hue is a beautiful auxiliary in working out the great impression to be conveyed, but is not the source nor the essence of that impression; it is little more than a visible melody, given to raise and assist the mind in the reception of nobler ideas—as sacred passages of sweet sound, to prepare the feelings for the reading of the mysteries of God.]

THE END.

APPENDIX.

I. Colour Photometry. See Sections 70A, 70B, 72.

I am indebted to the courtesy of Captain Abney, F.R.S., for an account of some valuable recent (1886-8) researches in Colour Photometry, made by him and Major-General Festing. I give here a brief abstract.

FIRST, with regard to the pure colours of the Spectrum. The method used was based on the principle of Rumford's Shadow Photometer. Two shadows of a rod were cast upon a screen, one shadow by any selected portion of the spectrum (formed from an electric light), the other shadow by a steady comparison-light (a candle), attached to a graduated scale. The distance of the comparison-light from the screen could be varied, and it was moved until the shadow it cast appeared of the same luminosity as the shadow cast by the spectral colour. It will be understood that the screen is jointly illuminated by the candle and by the spectral light, but that each shadow is lighted by the light which does not cast it. The colour of the screen, and the colours of the shadows, vary for the different spectral colours (Sections 224, 225), but the uncertainty which might have been expected, does not appear to arise. There seems to be but little difficulty in determining which of the two shadows is the lighter (or the darker), and so, when equality is established, we at once get a relation between the luminosity of the candle and the luminosities of the various spectral colours.

The different portions of the spectrum (referred to the fixed lines) were taken as abscissæ, and the luminosity of any portion of the spectrum was expressed by the length of the ordinate erected at that

portion. The line joining the upper ends of the ordinates is called the curve of luminosity, and the particular curve obtained by the observers (whose perception was very acute) was called the "normal" curve.

Instead of shifting the comparison-light, it was found better to have a fixed light, and to alter its intensity by rotating rapidly in front of it a disc with apertures, which could be closed to a greater or less degree. On trying to estimate the intensity of the different portions of the solar spectrum, a serious difficulty occurred owing to the variability of the source of light (the sun). This was very ingeniously overcome by comparing the spectral colours of sunlight, not with a separate fixed light, but with an unaltered portion of the same sunlight. The solar curve of luminosity closely resembles that obtained from the experiments on the electric light. In London, with an east wind, the intensity of the blue end of the spectrum diminishes, owing no doubt to the smoke haze then prevalent. (Section 52.)

If the maximum intensity (which occurs in the spectrum of the electric light in the yellow, a little to the more refrangible side of fixed line D) be taken as 100, the intensities at the fixed lines are about as follows: At B, 5; at C, 25; at D, 99; at E, 60; at b, 40; at F, 9; at G, ·65. In the prismatic spectrum the light falls off pretty evenly and rapidly from its maximum in the yellow down to the blue about F and the red between B and C, it then falls off more and more slowly towards the outer violet, and pretty quickly, but at a decreasing rate, towards the outer red.

The statement—that the luminosity of any mixture of coloured lights is the sum of the luminosities of its constituents (Section 74)—was fully confirmed by the shadow experiments.

It appears that the amount of light admitted to form the spectrum does not influence the form of the curve, and this would imply that, relatively to each other, the luminosities of the spectral colours do not alter, whether the spectrum be formed by a large or a small amount of light from the same source. This result does not appear to be consistent with Helmholtz's views. (Section 195.)

SECONDLY, with regard to pigmented surfaces. By a modification of the methods, the intensity of the light of the spectrum reflected from a coloured body—such as a pigment—was measured in terms of the light of the spectrum reflected from a white surface.

Also a gray being formed by rotating a disc composed of sectors of vermilion, emerald-green and ultramarine, and matched by a gray formed of white and black, it was found that the reduced luminosity curve of the white equalled the sum of the reduced luminosity curves of the three positive colours. (Sections 74 and 78.) (For details see the original paper, read before the Royal Society, 31st May, 1888.)

For some interesting observations made, with the shadow method, on colour-blind people, the original paper (Phil. Trans. 1886) should be referred to.

The deductions of Lord Rayleigh as to the action of the fine particles in a turbid medium (Section 47) were also confirmed by experiments made with the shadow photometer.

The above investigations throw a quite new light upon the obscure subject of colour photometry, introducing into it an exactitude of measurement hitherto unknown in the comparison of colours of *different* hues.

II. Transmission of Sunlight through the Atmosphere. (Sects. 46—60A.)

There is also an important paper by Captain Abney (in the Phil. Trans. for 1887) on the Transmission of Sunlight through the Earth's Atmosphere. Results of observations made in London, and at a height of 8,000 feet on the Riffel (Switzerland), are tabulated and compared. The law which holds good with turbid media, artificially prepared, is under ordinary circumstances obeyed by sunlight in passing through air; the longer waves are more freely transmitted than the shorter, because the latter are more scattered by reflection from the fine particles of water, dust, etc., suspended in the atmosphere. Comparing the intensities of the spectral colours transmitted on a summer day at the Riffel with those transmitted on a winter day in London, it was found

that, in the London spectrum, there was very little violet, only about one third of the blue, and less than half the green, but still four-fifths of the red, of the Riffel spectrum. The absorbent action upon the more refrangible rays is strikingly illustrated by the foregoing. Captain Abney is of opinion that small particles of water are the most efficient agents in diminishing the amount of transmitted light.

III. Permanence of Pigments. (Sect. 279.)

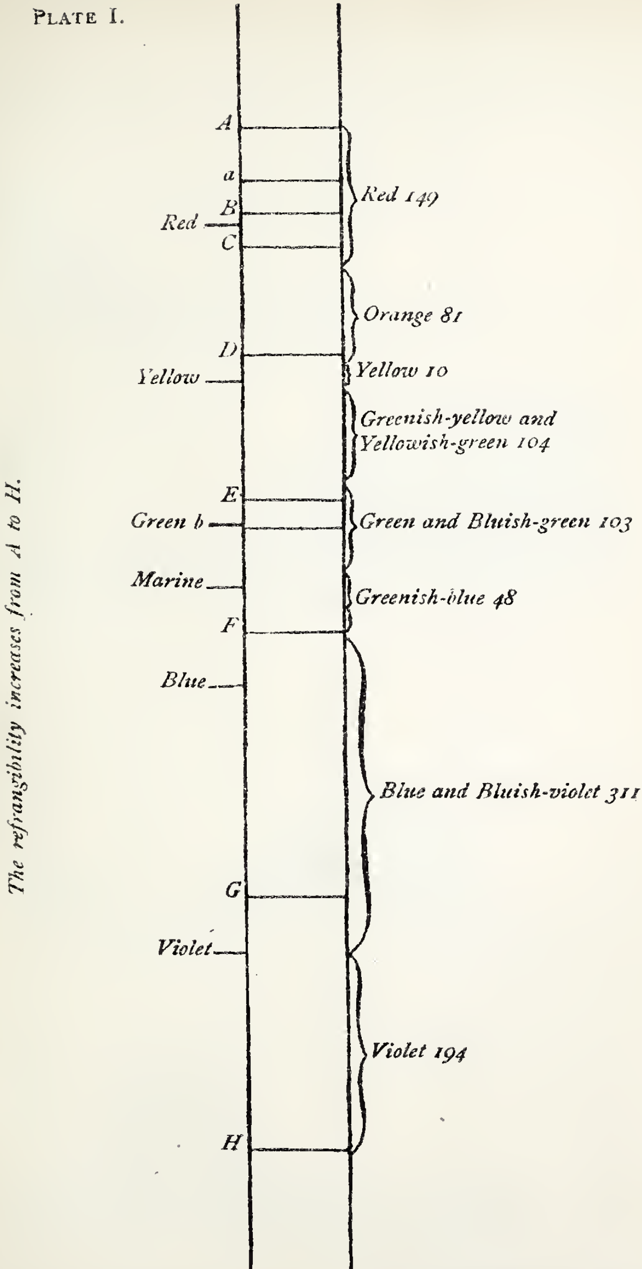
A Parliamentary Report on the action of light on Water-colours, by Captain Abney and Dr. Russell, is to be published very shortly. The results obtained, based upon laborious and most intelligent scientific investigation, are of the highest value, and mark an era in the history of the permanence of pigments. I very much regret that the Report is not yet accessible, so that I cannot give a summary of it here.

IV. Colour-Blindness. (Part VIII.)

From a recent Parliamentary Paper (Report on Colour-blindness in connection with the British Mercantile Marine, 1887) a few particulars may be of interest. It is found that one out of every 200 candidates, out of a total of 40,000 examined for officers' certificates, is so defective in his sense of colour that he cannot with safety be allowed to occupy a position where ability to distinguish the signal colours with readiness and confidence is absolutely indispensable. It will be understood that this low percentage is due to the fact that the class examined is a select one, and that the percentage rejected of those who do not belong to this class, is a good deal higher—nearly 7 per cent. Also, only very marked cases are rejected, the intermediate ones are passed.

In the most important of the tests, that in which the candidate was required to describe the colour of a light exhibited in a dark room, the standard green light was described as red in 107 cases, and the standard red as green in 24 cases, out of 139. With coloured cards, pink was described as green in 44 cases, drab as green in 51 cases, red as green in 17 cases, and green as drab in 19 cases, out of the same total.

D. DUNCAN AND SONS, SOUTH WALES PRINTING WORKS, CARDIFF.

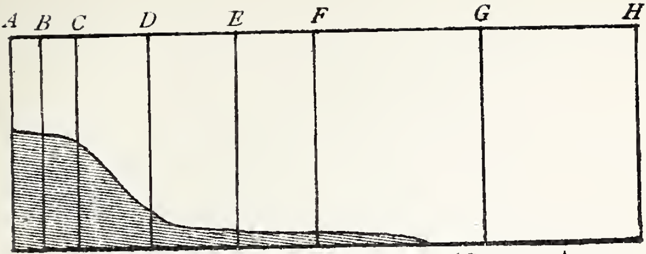


A, *a*, *B*, *C*, *D*, *E*, *b*, *F*, *G*, *H*, *are Fraunhofer Lines. (Sects. 9, 10, 11.)*

The Solar Spectrum of Flint Glass Prism. A to H supposed to be divided into 1,000 parts.

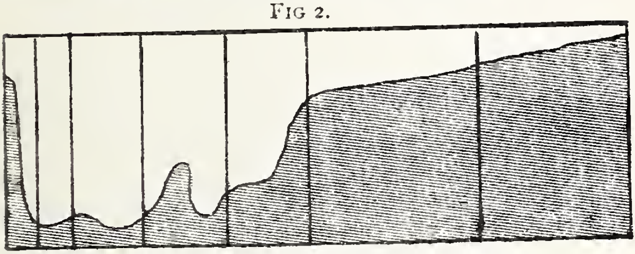
PLATE II.

FIG 1.



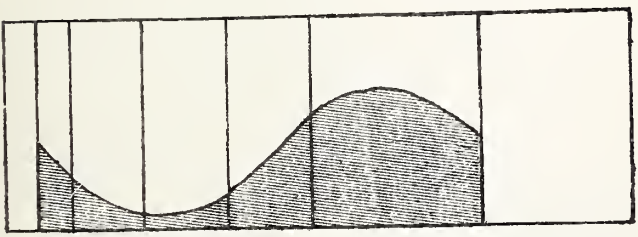
(Trans.) A certain Red Glass. (Sect. 17a.)

FIG 2.



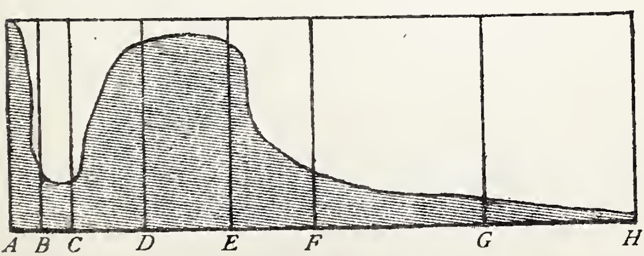
(Trans.) A certain Blue Glass. (Sect. 17a.)

FIG 3.



(Refl.) Cobalt Blue Paper between lines B and G. (Sect. 33.)

FIG 4.



(Refl.) Green leaf. (Sect. 27.)

Spectra. The shaded portions show the extent and intensity of the transmitted, or reflected, light. (Rood.)

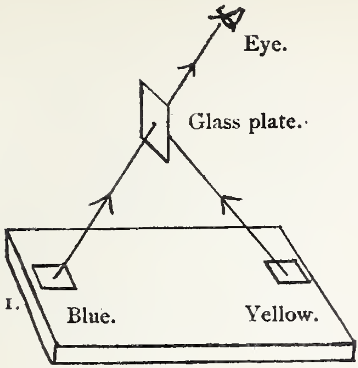


FIG I.

Mixture by combined reflection and transmission. (*Sect.* 77.)

For blue and yellow the result is white. (*Sect.* 98.)

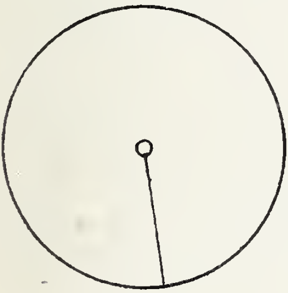
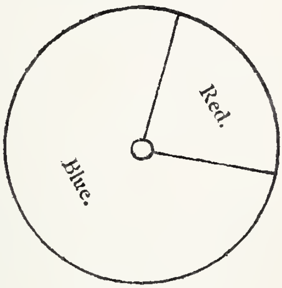


FIG 2.

Maxwell's Disc with radial slit. (*Sect.* 78.)



Compound disc, made of two discs, and showing 25 parts of red and 75 of blue. Appears bluish-purple on rotation. (*Sects.* 78 *and* 100.)

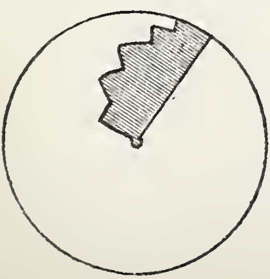
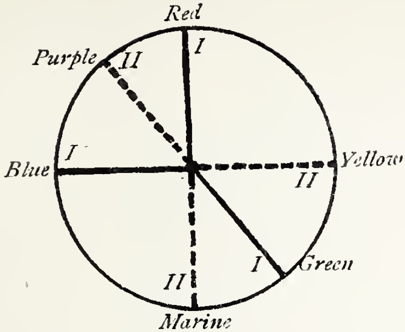


FIG 3.

Composite black sector superposed on white disc. On rotation, a series of grey rings (deepening to a central black circle) are seen. (*Sects.* 79, 100*b*, 208, 237.)

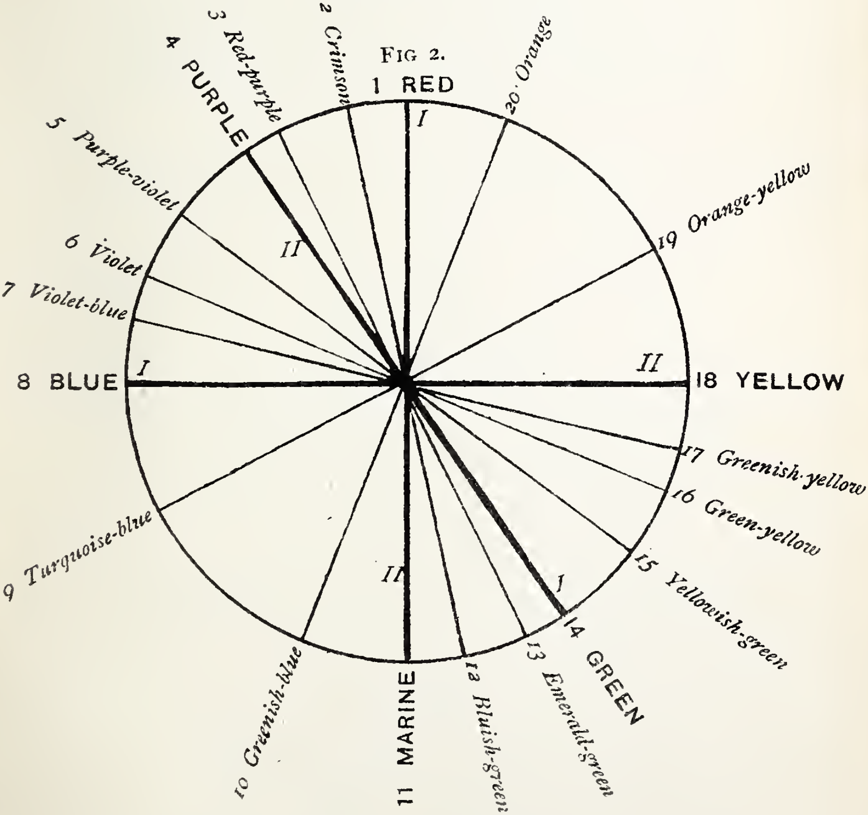
PLATE IV.

FIG I.



I I I Primaries.
II II II Secondaries.
(Sect. 155.)

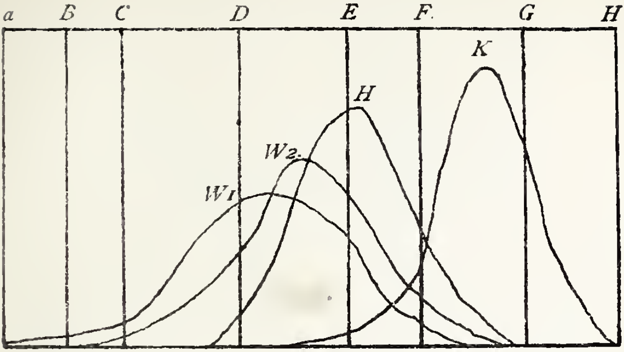
FIG 2.



Chromatic, Complementary, and Contrast, Circle. Ten pairs of Complementary Colours.
I I I Primaries. II II II Secondaries. 1 and 11, 2 and 12, &c., are Complementary Pairs. (Sects. 139, 207.)

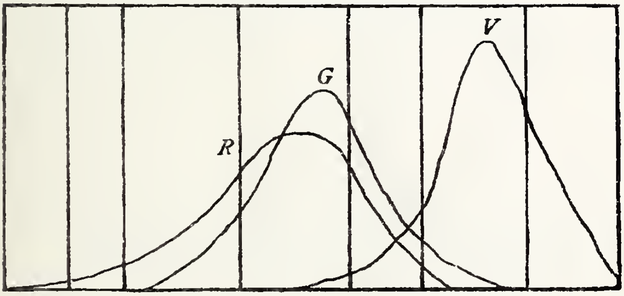
PLATE V.

FIG 1. (*Sects. 178a and 165.*)



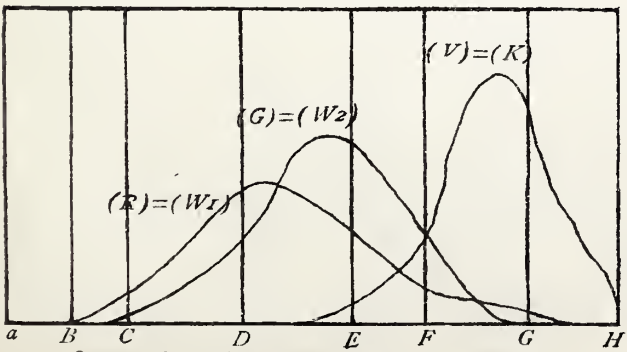
Elementary Sensation Curves for one-colour-seeing eyes, H; and for two types of two-colour-seeing eyes, K W1; K W2.

FIG 2. (*Sects. 178a and 143.*)



E S C for normal three-colour-seeing eyes.

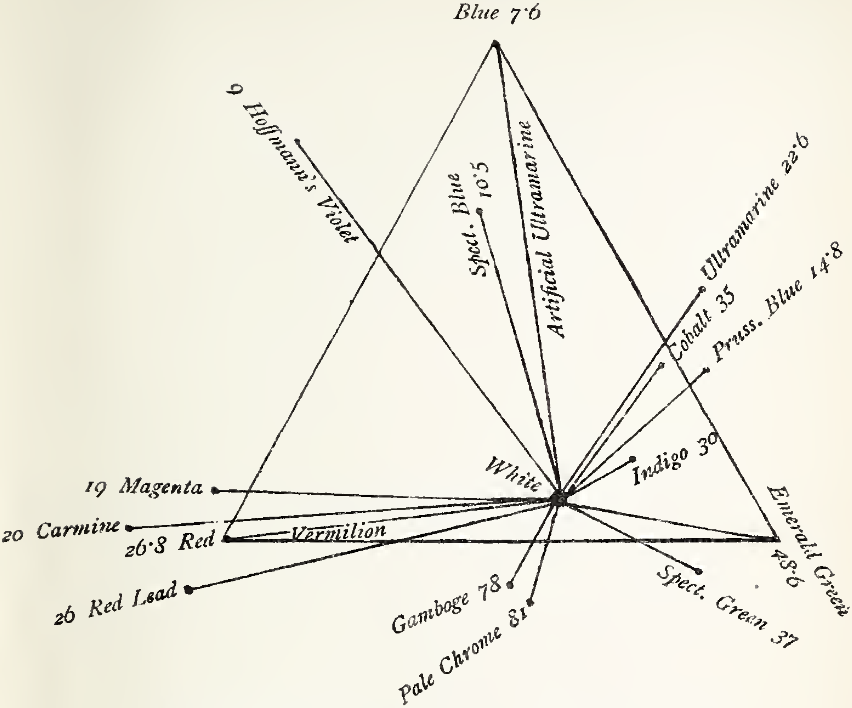
FIG 3. (*Sects. 178a and 143.*)



Curves of Fundamental Sensations. (*Koenig.*)

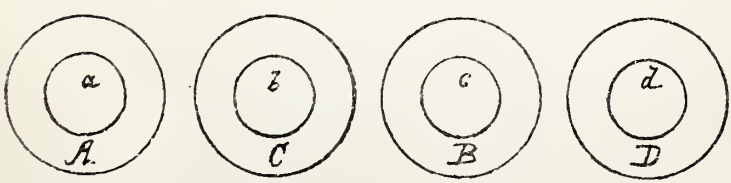
PLATE VI.

FIG I.



Maxwell's Triangle, reconstructed by Rood; the co-efficients denote the luminosities of the pigments, white paper being taken as 100. (Sects. 257-262.)

FIG 2.



Contrast. (Sect. 214a.)

12/80
KLX